William P. Morse

PROCEEDINGS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS

VOL. XXXVI—No. 1

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CIVIL ENGINEERS

(INSTITUTED 1852)

VOL. XXXVI—No. 1

JANUARY, 1910

Edited by the Secretary, under the direction of the Committee on Publications.

CONTENTS

NEW YORK 1910

American Society of Civil Engineers

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ON BITUMINOUS MATERIALS FOR ROAD CONSTRUCTION: W. W. Crosby, A. W. Dean, H. K. Bishop, A. H. Blanchard.

The House of the Society is open from 9 A.M. to 10 P.M. every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

HOUSE OF THE SOCIETY—220 WEST FIFTY-SEVENTH STREET, NEW YORK.

TELEPHONE NUMBER.....................5913 Columbus.

CABLE ADDRESS.........................."Ceas, New York."

Vol. XXXVI. JANUARY, 1910. No. 1.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PROCEEDINGS

This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS

CONTENTS

MINUTES OF MEETINGS

OF THE SOCIETY

December 15th, 1909.—The meeting was called to order at 8.30 P. M.; Past-President Alfred Noble in the chair; Chas. Warren Hunt, Secretary; and present, also, 239 members and 40 guests.

A paper by James H. Brace, Francis Mason, and S. H. Woodard, Members, Am. Soc. C. E., entitled "The New York Tunnel Extension of the Pennsylvania Railroad: The East River Tunnels," was presented by Mr. Brace. A paper by Henry Japp, M. Am. Soc. C. E., entitled "The New York Tunnel Extension of the Pennsylvania Railroad: Contractors' Plant for East River Tunnels," was presented by the author. Both papers were illustrated with lantern slides.

The papers were discussed by Messrs. Charles E. Fraser and Henry Japp.

The Secretary announced the following deaths:

William Metcalf, Past-President, elected Member, July 2d, 1873; died December 5th, 1909.

Edmund Alyth Rhys-Roberts, elected Associate Member, November 3d, 1897; died October 5th, 1909.

Charles Marshall Harris, elected Associate, January 8th, 1873; died October 28th, 1909.

Ernest Stearns Ball, elected Junior May 2d, 1905; died November 22d, 1909.

Adjourned.

January 5th, 1910.—The meeting was called to order at 8.30 P. M.; Vice-President George H. Pegram in the chair; Chas. Warren Hunt, Secretary; and present, also, 89 members and 27 guests.

The minutes of the meetings of November 17th and December 1st, 1909, were approved as printed in *Proceedings* for December, 1909.

A paper by Horace J. Howe, M. Am. Soc. C. E., entitled "Notes on the Replacing of the Superstructure of the Harlem Ship Canal Bridge," was presented by the author and illustrated with lantern slides.

The Secretary read a communication from Lincoln Bush, M. Am. Soc. C. E., on the subject, and the paper was discussed orally by Messrs. Martin Gay and St. John Clarke.

The Secretary announced the election of the following candidates on January 4th, 1910:

As Members.

Charles Raymond Baffrey, New York City.
Herbert Clark Hoover, London, England.
George Holbrooke Maurice, Harrisburg, Pa.
Harley Edson Reeves, Atkinson, Ill.
Addison Alexander Righter, Chicago, Ill.
Theodore Rosenberg, Glenwood Springs, Colo.
Rafael Alvarez Salas, Cali, Colombia.
Richard Edward Speakman, Brandon, Man., Canada.
Carlton Strong, Pittsburg, Pa.
Sledge Tatum, Washington, D. C.
Parker O Wright, Jr., Culebra, Canal Zone, Panama.

As Associate Members.

William Sibson Bake, Grand Rapids, Mich.
Benjamin Franklin Batchelder, Ravenna, Ohio.
Julius Montgomery Bischoff, St. Louis, Mo.
Henry Leo Connell, Brown Station, N. Y.

Homer Munro Derr, Brookings, S. Dak.
William Henry Dietrich, Shanghai, China.
Claude Sanford Haynes, Brooklyn, N. Y.
Roy Stevenson King, Dayton, Ohio.
John Christian Koch, Chicago, Ill.
Eugene Clyde LaRue, Salt Lake City, Utah.
George Benjamin Lorenz, Sacramento, Cal.
Carl Maughmer, Sacramento, Cal.
Jose Pires do Rio, New Orleans, La.
Walter Bowen Saunders, Malta, Mont.
Frederick Adolph Schrader, New York City.
John Francis Sullivan, New York City.
George Edward Tebbetts, Chicago, Ill.
Frank Leslie Tibbetts, Boston, Mass.
Stephen Barker Vernon, Syracuse, N. Y.
George Neville Wheat, San Antonio, Tex.
William Renfrew Wilson, Tientsin, China.

As Associate.

Ernest Frederick Hartmann, New York City.

As Juniors.

Hermon Yancy Gard, St. Joseph, Mo.
Harold Farnsworth Gray, Berkeley, Cal.
Thomas Hughes Holmes, Chicago, Ill.
Ralph Henry Jones, Spokane, Wash.
Hunter McClure, Savannah, Ga.
LeRoy McWethy, Hamilton City, Cal.
Charles Edward Merritt, Watertown, N. Y.
George Rufus Ogier, Denver, Colo.
Francis Sheridan O'Reilly, Wilkes-Barre, Pa.
Irving Wooster Patterson, Providence, R. I.
Arthur Richards, Gatun, Canal Zone, Panama.
Jesse Steele Ritchey, Manila, Philippine Islands.
Henry Arthur Seeley, Bridgeport, Conn.
Walter Farnsby Shaw, Syracuse, N. Y.
Arthur Louis Sherman, White Plains, N. Y.
Glenn Warner, Oakfield, N. Y.
Charles William Woodruff, Portland, Ore.

The Secretary announced the transfer of the following candidates on January 4th, 1910:

From Associate Member to Member.

Walter Buehler, St. Louis, Mo.
John Henry Cook, Paterson, N. J.

Park Andrew Dallis, Atlanta, Ga.
Isaac deYoung, Sault Ste. Marie, Mich.
Walter Joseph Graves, Sault Ste. Marie, Mich.
Isaac Wendell Hubbard, Philadelphia, Pa.
Charles Marcellus Pritchett, Manila, Philippine Islands.
George Freeman Rowell, Guild, Tenn.
George Otis Sanford, Williston, N. Dak.
Harold Clair Stowe, Brooklyn, N. Y.

From Associate to Associate Member.

Frederick Wilcock, Brooklyn, N. Y.

From Junior to Associate Member.

Clarence Arminger Bingham, Carlisle, Pa.
Edward Hutchins, East Walpole, Mass.
Ernest Anthony Moritz, Sunnyside, Wash.
Lionel Henry Peabody, Jr., Providence, R. I.
Percy Sawyer, Waukesha, Wis.
Edward Lee Soule, Berkeley, Cal.
Carl Tombo, New York City.

From Junior to Associate.

Harry Hurd Atwell, Ann Arbor, Mich.

The Secretary announced the following resignations as of December 31st, 1909:

Members: C. W. Curry, Charles Mayne, A. McC. Parker, Thomas W. Symons, A. Twyman, Arthur M. Waitt.

Associate Members: Herman Conrow, A. K. Tiernan, M. S. Towson.

Associates: J. R. Berthelet, William H. Cooper.

Juniors: Paul D. Bunker, John Earl Carpenter, C. C. English, E. J. Gugerty, C. D. Mercer, W. H. Ratcliff, Jr., Arthur G. Seabury, Max W. Wolff.

The Secretary announced the following deaths:

Charles Benjamin Dudley, elected Member, March 2d, 1892; died December 21st, 1909.

Jacobus Van der Hoek, elected Member, April 7th, 1897; died December 22d, 1909.

Adjourned.

OF THE BOARD OF DIRECTION

(Abstract)

January 4th, 1910.—President Bates in the chair; Chas. Warren Hunt, Secretary; and present, also, Messrs. Andrews, Brackett, Christie, Endicott, Hazen, Hodgdon, Horton, Kittredge, Macdonald, Noble, Pegram, Schneider, Swain, Thompson, and Tillson.

A payment of $10 000 on the principal of the mortgage debt was authorized.

Action was taken in regard to members in arrears for dues.

A report of the Board to the Society for the year 1909 was adopted.

A letter was received from Hiram Francis Mills, of Lowell, Mass., accepting his election as Honorary Member of the Society.

The resignations of 6 Members, 3 Associate Members, 2 Associates, and 8 Juniors were accepted, as taking effect December 31st, 1909.

Ballots for membership were canvassed, resulting in the election of 11 Members, 21 Associate Members, 1 Associate, and 17 Juniors, the transfer of 10 Associate Members to the grade of Member, 1 Associate to the grade of Associate Member, 7 Juniors to the grade of Associate Member, and 1 Junior to the grade of Associate.

Applications were considered, and other routine business was transacted.

Adjourned.

ANNOUNCEMENTS

The House of the Society is open from 9 A. M. to 10 P. M., every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

MEETINGS

February 2d, 1910.—8.30 P. M.—At this meeting two papers will be presented for discussion, as follows: "Underpinning the Cambridge Building, New York City," by T. Kennard Thomson, M. Am. Soc. C. E., and "Building Agreements," by William B. Bamford, Assoc. M. Am. Soc. C. E.

These papers were printed in *Proceedings* for December, 1909.

February 16th, 1910.—8.30 P. M.—At this meeting two papers will be presented for discussion, as follows: "The Effect of Alkali on Concrete," by George Gray Anderson, M. Am. Soc. C. E., and "Precarious Expedients in Engineering Practice," by John Hawkesworth, Assoc. M. Am. Soc. C. E.

Mr. Gray's paper was printed in *Proceedings* for December, 1909, and Mr. Hawkesworth's paper is printed in this number of *Proceedings.*

March 2d, 1910.—8.30 P. M.—A paper entitled "The Improved Water and Sewage Works of Columbus, Ohio," by John H. Gregory, M. Am. Soc. C. E., will be presented for discussion.

This paper is printed in this number of *Proceedings.*

SUBSCRIPTION PRICE TO THE PUBLICATIONS OF THE SOCIETY

The following subscription rates have been fixed by the Board of Direction for the publications of the Society:

Proceedings, ten Numbers per annum, $8. Price for single numbers, $1.

Transactions, four Volumes per annum, $12. Price for single volumes, $4.

On the above prices there is a discount of 25% to members who desire extra copies of any of these publications, to Libraries, and to Book-dealers.

There is also an additional charge per annum, to cover foreign postage, of 75 cents for *Proceedings* and $1 for *Transactions,* or 8 cents and 25 cents, respectively, for single numbers.

A special subscription rate has been fixed by the Board for the *Proceedings* of the Society for the benefit of Students in Technical Schools. This rate is $4.50 per annum, and is available to any *bona fide* student of any technical school.

MEETINGS OF THE SAN FRANCISCO ASSOCIATION OF MEMBERS, AM. SOC. C. E.

The San Francisco Association of Members of the American Society of Civil Engineers holds regular bi-monthly meetings, with banquet and weekly informal luncheons. The former are held at 6 P. M., at the Fairmont Hotel, on the third Friday of February, April, June, August, October, and November, and also on the third Wednesday of December, the latter being the Annual Meeting of the Association.

Informal luncheons are held at 12.15 P. M. every Wednesday, and the place of meeting may be ascertained by communicating with the Secretary of the Association, E. T. Thurston, Jr., Assoc. M. Am. Soc. C. E., 623 Wells Fargo Building.

The by-laws of the Association provide for the extension of hospitality to any members of the Society who may be temporarily in San Francisco, and any such member will be gladly welcomed as a guest of the Association at any of the above meetings, if he will notify the Secretary that he is in San Francisco.

PAPERS AND DISCUSSIONS

It is hoped that members and others who take part in the discussion of the papers presented will revise their remarks promptly, and that all written communications from those who cannot attend the meetings will be sent in at the earliest possible date after the issue of a paper in *Proceedings*. The quarterly issue of volumes of *Transactions* is dependent on the closing of discussions, and the co-operation of the membership is now more necessary in this matter than heretofore, because a definite date of issue for each volume must be maintained.

All papers accepted by the Publication Committee are classified by the Committee with respect to their availability for discussion at meetings.

Papers, which, from their general nature, appear to be of a character suitable for oral discussion, will be published as heretofore in *Proceedings,* and set down for presentation to a future meeting of the Society, and, on these, oral discussion, as well as written communications, will be solicited.

All papers which do not come under this heading, that is to say, those which, from their mathematical or technical nature, in the opinion of the Committee, are not adapted to oral discussion, will not be scheduled for presentation to any meeting. Such papers will be published in *Proceedings* in the same manner as those which are to be presented at meetings, but written discussions, only, will be requested for subsequent publication in *Proceedings* and with the paper in the volumes of *Transactions.*

PRIVILEGES OF ENGINEERING SOCIETIES EXTENDED TO MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Members of the American Society of Civil Engineers will be welcomed by the following Engineering Societies, both to the use of their Reading Rooms and at all Meetings:

American Institute of Mining Engineers, 29 West Thirty-ninth Street, New York City.

Associação dos Engenheiros Civis Portuguezes, Lisbon, Portugal.

Australasian Institute of Mining Engineers, Melbourne, Victoria, Australia.

Boston Society of Civil Engineers, 715 Tremont Temple, Boston, Mass.

Brooklyn Engineers' Club, 117 Remsen Street, Brooklyn, N. Y.

Canadian Society of Civil Engineers, 413 Dorchester Street, West, Montreal, Que., Canada.

Civil Engineers' Society of St. Paul, St. Paul, Minn.

Cleveland Engineering Society, 718 Caxton Building, Cleveland, Ohio.

Cleveland Institute of Engineers, Middlesbrough, England.

Colorado Association of Members, Am. Soc. C. E., H. J. Burt, Secy., 235 Equitable Building, Denver, Colo.

Engineers' and Architects' Club of Louisville, Ky., 303 Norton Building, Fourth and Jefferson Streets, Louisville, Ky.

Engineers' Club of Baltimore, Baltimore, Md.

Engineers' Club of Minneapolis, 17 South Sixth Street, Minneapolis, Minn.

Engineers' Club of Philadelphia, 1317 Spruce Street, Philadelphia, Pa.

Engineers' Club of St. Louis, 3817 Olive Street, St. Louis, Mo.

Engineers' Club of Toronto, 96 King Street, West, Toronto, Ont., Canada.

Engineers' Society of Pennsylvania, 219 Market Street, Harrisburg, Pa.

Engineers' Society of Western Pennsylvania, 803 Fulton Building, Pittsburg, Pa.

Institute of Marine Engineers, 58 Romford Road, Stratford, London, E., England.

Institution of Engineers of the River Plate, Buenos Aires, Argentine Republic.

Institution of Naval Architects, 5 Adelphi Terrace, London, W. C., England.

Junior Institution of Engineers, 39 Victoria Street, Westminster, S. W., London, England.

Koninklijk Instituut van Ingenieurs, The Hague, The Netherlands.

Louisiana Engineering Society, 321 Hibernia Bank Building, New Orleans, La.

Memphis Engineering Society, Memphis, Tenn.

Midland Institute of Mining, Civil and Mechanical Engineers, Sheffield, England.

Montana Society of Engineers, Butte, Montana.

North of England Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne, England.

Oesterreichischer Ingenieur= und Architekten=Verein, Eschenbachgasse 9, Vienna, Austria.

Pacific Northwest Society of Engineers, 803 Central Building, Seattle, Wash.

Rochester Engineering Society, Rochester, N. Y.

Sachsischer Ingenieur= und Architekten=Verein, Dresden, Germany.

Sociedad Colombiana de Ingenieros, Bogota, Colombia.

Societe des Ingenieurs Civils de France, 19 Rue Blanche, Paris, France.

Society of Engineers, 17 Victoria Street, Westminster, S. W., London, England.

Svenska Teknologforeningen, Brunkebergstorg 18, Stockholm, Sweden.

Tekniske Forening, Vestre Boulevard 18–1, Copenhagen, Denmark.

Western Society of Engineers, 1737 Monadnock Block, Chicago, Ill.

SEARCHES IN THE LIBRARY

In January, 1902, the Secretary was authorized to make searches in the Library, upon request, and to charge therefor the actual cost to the Society for the extra work required. Since that time many searches have been made, and bibliogaphies and other information on special subjects furnished.

The resulting satisfaction, to the members, who have made use of the resources of the Society in this manner, has been expressed frequently, and leaves little doubt that, if it were generally known to the membership that such work would be undertaken, many would avail themselves of it.

The cost is trifling compared with the value of the time of an engineer who looks up such matters himself, and the work can be performed quite as well, and much more quickly, by persons familiar with the Library.

In asking that such work be undertaken, members should specify clearly the subject to be covered, and whether references to general

books only are desired, or whether a complete bibliography, involving search through periodical literature, is desired.

In reference to this work, the Appendix* to the Annual Report of the Board of Direction for the year ending December 31st, 1906, contains a summary of all searches made to that date.

LOCAL ASSOCIATIONS OF MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Colorado Association

(Abstract of Minutes of Meeting)

December 11th, 1909.—The regular meeting of the Colorado Association of Members, Am. Soc. C. E., was called to order at 8.30 P. M.; H. S. Crocker, President, in the chair; H. J. Burt, Secretary; and present, also, 11 members and 6 guests.

The minutes of the November meeting were read and approved.

Professor Russel D. George, State Geologist, addressed the Association on "State Geological Survey," and the subject was discussed by Messrs. Prince, Raynor, Carstarphen, Ketchum, Holbrook, and Burt.

Adjourned.

* *Proceedings*, Vol. XXXIII, p. 20 (January, 1907).

ANNUAL REPORT OF THE BOARD OF DIRECTION FOR THE YEAR ENDING DECEMBER 31st, 1909.

In compliance with the Constitution, the Board of Direction presents its report for the year ending December 31st, 1909.

MEMBERSHIP.

The changes in membership are shown in the following table:

Grade.	Jan. 1st, 1909.			Jan. 1st, 1910.			Losses.				Additions.		Totals.	
	Resident.	Non-Resident.	Total.	Resident.	Non-Resident.	Total.	Transfer.	Resignation.	Dropped.	Death.	Transfer.	Election.	Loss.	Gain.
Honorary Members	.....	8	8	.....	8	8	....	..	..	1	....	1	1	1
Corresponding Members	.....	2	2	.....	2	2	....	..	..	..	....	.....	....	....
Members	525	1 845	2 370	564	2 003	2 567	....	10	1	36	*82	¶162	47	244
Associate Members	401	1 218	1 619	430	1 399	1 829	77	8	2	6	†71	232	93	303
Associates	68	93	161	71	93	164	3	3	..	2	‡2	9	8	11
Juniors	152	490	642	151	550	701	75	11	6	3	....	154	95	154
Fellows	7	15	22	6	15	21	....	..	..	1	....	.....	1	....
Total	1 153	3 671	4 824	1 222	4 070	5 292	155	32	9	49	155	558	245	713

* 77 Associate Members, 2 Associates, and 3 Juniors.
† 1 Associate and 70 Juniors.
‡ 2 Juniors.
¶ 1 Reinstatement.

As will be seen from the above table, the net increase during the year has been 468.

The following analysis of the growth of the Society may prove of interest:

Thirty-nine years ago, on December 31st, 1870, the total membership of the Society was 243.

Twenty-four years later, December 31st, 1894, the total membership was 1 773, the average yearly net increase for this period being $63\frac{3}{4}$.

The yearly increase in membership for the past fifteen years follows:

	1895...114	1900...138	1905.. 336
	1896...103	1901...191	1906...378
	1897....59	1902...184	1907...494
	1898....47	1903...212	1908...413
	1899...103	1904...279	1909...468
Total for five-year period	426	1 004	2 089
Average for five-year period	85	201	418
Rate of increase for five-year period	24%	$45\frac{6}{10}$%	$65\frac{2}{10}$%
Equivalent yearly rate of increase	$4\frac{4}{10}$%	$7\frac{8}{10}$%	$10\frac{6}{10}$%

This growth seems quite remarkable, in view of the fact that requirements for admission have been somewhat increased, and that the general financial depression which occurred during the last five-year period does not appear to have affected the constantly increasing number of applications received.

The membership has doubled in the last 7½ years, and should the rate of increase of the past five years continue, the total membership will exceed 10 000 in less than seven years.

The number of applications received during 1909 was 861: 651 for admission, and 210 for transfer.

The losses by death reported during the year number 49, and are as follows:

Honorary Members (1): William Price Craighill.

Members (36): George Adgate, William Creelman Ambrose, Henry Furlong Baldwin, George Thomas Barnsley, George H. Bishop, Howard Breen, Henry Waller Brinckerhoff, Leffert Lefferts Buck, Francis Smith Burrowes, Daniel Dawson Carothers, James Henry Covode, Frank Leslie Davis, John Bagley Dimmick, Charles Benjamin Dudley, Robert L. Engle, Elstner Fisher, George Samuel Gatchell, Charles Sewall Gowen, Joseph Marshall Graham, George Porter Hilton, William Charles Kernot, Charles MacRitchie, William Metcalf, Charles Morton, Mace Moulton, William Parker, Emile Theodore Quinette de Rochemont, Lewis Frederick Rice, Henry Brown Richardson, Albert Stanley Riffle, Andrew Rosewater, James Gardner Sanderson, Julius William Schaub, Henry Maynadier Steele, Joseph Nelson Tubbs, James Eager Willard.

Associate Members (6): Carl William Birch-Nord, Charles Herbert Deans, George Harrison French, August Mayer, Liberty Gilbert Montony, Edmund Alyth Rhys-Roberts.

Associates (2): Charles Marshall Harris, John Arnold Ubsdell.

Juniors (3): Ernest Stearns Ball, Olin McClintock Boyle, Jr., Walter Lorton Dusenberry.

Fellows (1): Amzi Lorenzo Barber.

LIBRARY.

The total contents of the Library, and the increase during the year, are shown in the following statement:

	Total Contents.	Increase during 1909.
Bound volumes	18 593	1 003
Unbound volumes	36 243	1 843
Specifications	6 673	40
Maps, photographs and drawings	4 242	152
Total	65 751*	3 038

*Owing to an error made in the last report of the Board, this figure does not agree with the total therein given, plus the number of this year's accessions.

Of these accessions, 703 were donations received in answer to special requests, 81 were donations from publishers; 2 094 were donations received in regular course, and 160 were purchased.

The value of accessions to the Library during the year is as follows, each accession having been valued separately as received:

2 878 Donations and exchanges (estimated value)	$2 277.70
160 Volumes purchased (cost)	499.65
Binding 372 volumes	463.15
Total	$3 240.50

The following amounts have been expended upon the Library during the year:

Purchases, subscription and binding	$962.80
Fixtures, supplies and sundries	171.19
Total	$1 133.99

The number of titles in the Library is 24 187.

The total attendance in the Reading Room and Library during the year was 4 449.

During the year 68 new bibliographies (containing 1 675 separate references) have been made, and copies of 16 searches made in previous years have been furnished, 5 of these having been brought up to date. The total cost of this work, $311.82, has been charged to those for whom it was undertaken.

Early in the year the additional tier of book stacks mentioned in the last report of the Board, was installed at a cost of $4 309. The capacity of the Stack Room was increased 100% by this addition, which it is believed provides shelf room for at least ten years to come. The use of these new shelves necessitated the re-arrangement of the entire Library, which has been accomplished during the year.

PUBLICATIONS.

During the year ten numbers of *Proceedings* have been issued regularly and four volumes of *Transactions* (instead of two as heretofore) have appeared.

In *Proceedings* the list of references to current engineering literature has been continued, and has covered 88 pages and contained 3 357 classified references to periodicals.

The stock of the various publications of the Society kept on hand for the convenience of members and others now amounts to 149 348

copies, the cost of which to the Society for paper and presswork only has been $20 552.49.

During the year, 12 441 volumes of *Transactions* have been bound for members and others in the standard half-morocco and cloth bindings.

Summary of Publications for 1909.

	Issues.	Average Edition.	Total Pages.	Plates.	Cuts.
Transactions (Volumes)........	4	5 525	2 182	125	370
Proceedings (Monthly Numbers).	10	5 605	1 980	123	229
Constitution and List of Members	1	6 000	372	...	1
Totals..............	15	....	4 534	248	600

The cost of publications has been:

For Paper, Printing, etc., *Transactions* and *Proceedings*..	$20 696.69
For Plates and Cuts..............................	2 773.14
For Boxes, Mailing Lists, Copyright and Sundry Expenses.	1 088.71
For 11 090 Extra Copies of Memoirs and Papers..........	1 148.80
For 15 300 Copies of Pamphlet Conservation of Natural Resources	569.00
For List of Members..............................	1 725.76
Total......................................	$28 002.10
Deduct amount received from sale of publications.........	4 665.39
Net cost of publications for 1909...............	$23 336.71

A comparison of these figures with those given in the report of the Board for last year shows that in 1909 there were published in *Transactions* and *Proceedings* 965 more pages, and 70 more illustrations, than in 1908. These figures, however, do not show the increase of the four-volume-per-year over the two-volume-per-year system, because, in order to be able to issue four volumes in 1909, the amount of matter issued in *Proceedings* for 1908 was greatly increased over that of previous years. In order, therefore, to indicate the real increase in the amount of reading matter issued under the present practice, a comparison should be made with similar figures for the year 1907. This shows an increase of 1 280 pages, and of 326 illustrations, and that the additional gross cost was $8 038.55.

Attention is called to the variety of subjects treated in the papers making up the four volumes of *Transactions* issued during the year.

There were 39 separate papers included in these volumes, and among the subjects discussed were: Irrigation; Hydraulics; Hydro-electric Development; Waterway Improvement; Stream Flow; Flood

Prevention; Docks and Harbors; Foundations; Fire Resistant Construction of Buildings; Sewer Systems; Electric Railways and Trolley Construction; Material for Bridges and Viaducts and their Construction; Water-works Valuation; Water Purification; Tanks and Stand-Pipes; Masonry Dams; Passenger Elevators; Concrete; Cement and Cement Mortar; Weights of Freight Trains; Road Building; Cost Keeping; Steel Sheet Piling; Concrete Piles; Caisson Disease; Railway Surveys; Arch Construction; Tests of Structural Material; Copyright on Technical Drawings; and The Status of the Engineer.

In addition to these, papers have had a preliminary publication in *Proceedings* during the year on Tunnel Construction; Water Supply for The Panama Canal; Use of the Current Meter; Freight Train Traction; Paving Practice; Hydraulic Turbine Efficiency; Reinforced Concrete Construction; Underpinning of Buildings; Building Agreements; Bridges; River Regulation; Land Reclamation; Reservoir Outlets; and Water Purification.

MEETINGS.

During the year 23 meetings have been held as follows: At the Annual Meeting, 2; at the Annual Convention, 3; and 18 other meetings held at the Society House.

At these meetings there were presented 29 formal papers, 13 of which were illustrated with lantern slides, besides which there were 3 topical discussions. There were also 8 papers published in *Proceedings* which were not presented for discussion at any meeting of the Society. The number of members and others who took part in the preparation of, or discussion of, these papers was 214.

The Forty-first Annual Convention was held at Bretton Woods, N. H.

The total attendance at the 23 meetings held was about 4 050. The registered attendance at the Annual Meeting was 726, and at the Annual Convention 177 (includes members only), but there were many members and guests present at all of these meetings who failed to register.

MEDALS AND PRIZES.

For the year ending with the month of July, 1908, prizes were awarded as follows:

The Norman Medal to C. C. Schneider, Past-President, Am. Soc. C. E., for his paper entitled "Movable Bridges."

The Thomas Fitch Rowland Prize to Edward E. Wall, M. Am. Soc. C. E., for his paper entitled "Water Purification at St. Louis, Mo."

The Collingwood Prize for Juniors to D. W. Krellwitz, Jun. Am. Soc. C. E. (now Assoc. M. Am. Soc. C. E.), for his paper entitled "Reinforced Concrete Towers."

FINANCES.

During the year the mortgage debt has been reduced by a payment of $10 000, and now amounts to $145 000. A further payment of $10 000 has been ordered, and it is expected will be made between the date of this report and that of the Annual Meeting, so that practically at the beginning of this year the debt will be reduced to $135 000. The term of the original mortgage having expired, a new loan has been arranged for on very favorable terms.

The attention of members is invited to the Secretary's statement of receipts and disbursements, and to the general balance sheet which accompanies it, in which the financial condition of the Society is shown.

The reports of the Secretary and Treasurer are appended.

By order of the Board of Direction,

CHAS. WARREN HUNT,

Secretary.

NEW YORK, JANUARY 4TH, 1910.

GENERAL BALANCE SHEET, DECEMBER 31st, 1909.

ACCOMPANYING THE REPORT OF THE SECRETARY.

ASSETS.			LIABILITIES.		
Three Lots (estimated value)		$330 000.00	Dues for 1910 paid in advance	$24 503.59	
Society Building (cost)		171 362.23	Advance subscriptions, etc.	319.00	
Furniture (cost)		18 753.24			$24 822.59
Publications on hand (inventoried cost value)		20 552.49	Mortgage Debt and Loan		145 000.00
Library:			Funds invested in Society House, Lots and Library	$26 730.78	
Cash expended for books, etc.	$13 740.79		Surplus	463 631.57	
Donations, estimated value	55 965.54				490 362.35
		69 706.33			
Due from Members	$4 901.53				
Due from Non-Members	240.45				
		5 141.98			
Cash		44 668.67			
		$660 184.94			$660 184.94

We have examined the books and accounts of the American Society of Civil Engineers, for the year ended December 31, 1909, and certify that the foregoing Balance Sheet is in accordance therewith, and, in our opinion, correctly states the condition of the Society's affairs, as shown by the books.

79 WALL STREET, NEW YORK.
JANUARY 15, 1910.

MARWICK, MITCHELL & Co.,
Chartered Accountants.

REPORT OF THE SECRETARY FOR THE

To the Board of Direction of the

Gentlemen:—I have the honor to present a statement of Receipts 31st, 1909. I also append a general balance sheet showing the condition

Receipts.

Balance on hand December 31st, 1908, in Bank, Trust Company, and in hands of Treasurer		$33 082.60
Entrance Fees	$13 856.95	
Current Dues	56 548.24	
Past Dues	2 175.07	
Advance Dues	24 503.59	
Compounding Dues	250.00	
Certificates of Membership	563.44	
Badges	2 661.19	
Sales of Publications	4 665.39	
Library	363.82	
Annual Meeting	1 277.30	
Binding	9 725.42	
Interest	961.70	
Miscellaneous	594.30	
		118 146.41
		$151 229.01

YEAR ENDING DECEMBER 31st, 1909.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

and Disbursements for the fiscal year of the Society, ending December of the affairs of the Society.

Respectfully submitted,
CHAS. WARREN HUNT,
Secretary.

DISBURSEMENTS.

Salaries of Officers	$12 799.92	
Mileage of Directors	714.84	
Clerical Help	14 705.70	
Caretaking	1 782.83	
Publications	28 002.10	
Postage	6 999.42	
General Printing and Stationery	2 585.15	
Library	962.80	
Library Maintenance	171.19	
Badges	2 260.75	
Certificates of Membership	357.20	
Binding	6 656.29	
Prizes	176.45	
Convention	444.76	
Annual Meeting	1 924.30	
Maintenance of House	272.83	
Heat, Light and Water	1 132.98	
Betterments	110.00	
Furniture	587.42	
Work of Committees	99.50	
Interest and Insurance	7 500.81	
Building	5 121.50	
Bond and Mortgage (Payment on Principal)	10 000.00	
Current Business	906.06	
Petty Expenses	195.32	
Members' Accounts	90.22	
		$106 560.34
Balance on hand, December 31st, 1909:		
In Union Trust Company	$18 946.11	
In Garfield National Bank	24 222.56	
In hands of Treasurer	1 500.00	
		44 668.67
		$151 229.01

REPORT OF THE TREASURER.

In compliance with the provisions of the Constitution, I have the honor to present the following report for the year ending December 31st, 1909:

Balance on hand December 31st, 1908		$33 082.60
Receipts from current sources, January 1st to December 31st, 1909		118 146.41
Payment of Audited Vouchers for Current Business, January 1st to December 31st, 1909	$91 438.84	
Payment on principal of bond and mortgage	10 000.00	
Payment for new bookstacks, property encroachment, etc	5 121.50	
Balance on hand December 31st, 1909:		
In Union Trust Company $18 946.11		
In Garfield National Bank 24 222.56		
In hands of the Treasurer 1 500.00	44 668.67	
	$151 229.01	$151.229.01

Respectfully submitted,

Jos. M. Knap,
Treasurer, Am. Soc. C. E.

New York, January 4th, 1910.

ACCESSIONS TO THE LIBRARY

(From December 7th, 1909, to January 11th, 1910)

DONATIONS*

POWER, HEATING AND VENTILATION.

A Treatise for Designing and Constructing Engineers, Architects and Students. By Charles L. Hubbard. Cloth, 9 x 6 in., illus., 3v., 11 + 647 pp. Brattleboro, Vt., The Technical Press, 1908-09. $5.00.

The preface states that this work had its beginning in a pocket notebook, which, in turn, formed the basis of articles appearing in the technical press, and these, combined with new material, form the present treatise, which covers the design, construction, and management of power and heating plants. The subject of power is treated more especially from the steam side. The subject of heating is taken up quite fully and includes the warming and ventilating of all classes of buildings, from a small furnace-heated dwelling to buildings with central plants of the largest size. The Contents are: Part I, Boiler Room Equipment. Heat; Steam; Boiler Horse-Power; Types of Boilers; Design of Tubular Boilers; Boiler Furnaces; Boiler Settings; Chimneys; Mechanical Draft; Liquid Fuel; Boiler Accessories; Pipe and Fittings; Valves; Special Apparatus; Boiler Corrosion; Care and Management of Steam Boilers. Part II, Power and Lighting. Theory of the Steam Engine; Types of Engines; Condensers; Steam and Feed Piping; Electricity; Generators; Electric Motors; Electric Lighting; Care and Management of Steam Engines and Generators. Part III, Heating and Ventilation. Systems of Warming; Ventilation; Heat Loss from Buildings; Furnace Heating; Direct Steam Heating; Indirect Steam Heating; Direct Hot-Water Heating; Indirect Hot-Water Heating; Forced Hot-Water Circulation; Fans; Forced Blast Heating and Ventilation; Exhaust Steam Heating; Electric Heating; Special Devices; Heating and Ventilating Different Types of Buildings; Care and Management of Heating and Ventilation Plants.

THE POLAR PLANIMETER.

How It Is Used, and How It Operates; A Simple Treatise. By Frank J. Gray. Paper, 7 x 4¾ in., illus., 8 + 57 pp. London, St. Bride's Press, Ltd., 1909. 1 shilling net.

The author believes that, up to this time, there has been no simple, generally intelligible, step-by-step explanation of the polar planimeter for the non-mathematical man, and that, therefore, a want is filled by the publication in book form of the present treatise, which has already appeared serially in *The Surveyor and Municipal Engineer*. The treatment is professedly practical and along easy lines of thought. The Contents are: Introduction; The Movements and Their Effect; Experiments on Sectors; Experiments on Circles; Computation of Irregular Figures; Conclusion.

CONCRETE BRIDGES AND CULVERTS.

For Both Railroads and Highways. By H. Grattan Tyrrell. Leather, 6¾ x 4½ in., illus., 11 + 251 pp. Chicago and New York, The Myron C. Clark Publishing Co.; London, E. & F. N. Spon, Ltd., 1909. $3.00 net.

In the preparation of this manual, the author states that he has endeavored to eliminate mathematical formulas as far as possible, and to present the subject in the simplest manner, only such material being given as is required directly in the design and construction of ordinary concrete or masonry arches. The designs and data tables for culverts and trestles are stated to be original with the author, the result of his own practice in the design and construction of railroad structures, and are here presented for the first time. The Contents are: Part I, Plain Concrete Arch Bridges; Part II, Reinforced Concrete Arch Bridges; Part III, Highway Beam Bridges; Part IV, Concrete Culverts and Trestles; Index.

*Unless otherwise specified, books in this list have been donated by the publisher.

THE STEAM ENGINE.

A Concise Treatise for Students and Engineers. By Charles H. Benjamin. Cloth, 9 x 6 in., illus., 6 + 316 pp. Brattleboro, Vt., The Technical Press, 1909. $3.00.

In his preface the author describes his book as designed primarily for a text-book rather than as a reference for engineers, and states that it has been his purpose to explain the elementary principles of heat engines so that they might be readily understood by the student, and to show the application of these principles in the design, construction, and operation of modern reciprocating engines. He states further that, perhaps, more attention has been paid to practical problems than to theoretical ones, and more to the questions of the engine user and less to those of the scientist. Attention is called to the chapter on Specifications and Costs as containing some new material. The Contents are: Introduction; Elementary Principles; The Simple Steam Engine; The Thermodynamics of Air; The Thermodynamics of Steam; Valve and Link Motions; Indicators and Indicator Diagrams; Compound Engines; Governors; Fly Wheels; Steam in the Cylinder; Condensers and Heaters; Piping and Flow of Steam; Steam Engine Performance; Steam Engine Design; Specifications and Costs; Appendix—Steam Tables, Weight of Water, Ammonia Table, Hyperbolic Logarithms; Index.

POWER RAILWAY SIGNALLING.

By H. Raynar Wilson. Cloth, 12 x 9½ in., illus., 12 + 342 pp. London, The Publishers of *The Railway Engineer,* 1909. 18 shillings. (Donated by the Author and Publishers.)

This volume is No. 5 in "The Railway Series of Text Books and Manuals By Railway Men For Railway Men and Others." It is written as a companion work for the author's previous volume, "Mechanical Railway Signalling," and includes such matters as "lock and block," single-line working, etc. The field covered is, the preface states, a limited one, but its importance is vast, and the author is satisfied that he has described every known system for working single lines, of operating automatic signals, and for the actuation of switches and signals by power. It is further stated that the author gained most of his information as to American and Continental signalling first-hand. Part of the material originally appeared in *The Railway Engineer.* The Contents are: Instruments; Lock and Block, General Considerations; Lock and Block, British Systems; Lock and Block, Foreign Systems; Contact-Makers, Slots, Replacers, Detectors and Insulated Joints; Interlocking Opening Bridges; Working of Single Lines, General Considerations; Working of Single Lines, Tablet Systems; Working Single Lines, Electric Train Staffs; Working Single Lines, Automatic Signals and Other Methods; Automatic Signalling, Its Purpose; Automatic Signals; Automatic Signals, Installations on Steam-Worked Railways; Automatic Signals, Installations on Electrically-Worked Railways; Signals for Electric Tramways; Accessories for Automatic Signalling; Locomotive Cab Signals and Automatic Train Controls; Signalling and Interlocking Power Plants, Their Purpose; Electro-Pneumatic Power Plants; Low Pressure Pneumatic Power Plants; All-Electric Power Plants; Electro-Mechanical Power Plants; Hydraulic Power Plants; Appendix A, One-Wire Three Indication Block Instrument, Moore and Powles' Patent; Appendix B, Automatic Signals, Great Western Railway; Appendix C, Central Station, Glasgow, Caledonian Railway; Appendix D, Rules Relating to Automatic Signals; Index.

COST KEEPING AND MANAGEMENT ENGINEERING.

A Treatise for Engineers, Contractors, and Superintendents Engaged in the Management of Engineering Construction. By Halbert P. Gillette and Richard T. Dana, Members, Am. Soc. C. E. Cloth, 6 x 9 in., illus., 14 + 346 pp. New York and Chicago, The Myron C. Clark Publishing Co.; London, E. & F. N. Spon, Ltd., 1909. $3.50 net.

The authors state that this book is intended to assist engineers, contractors, and superintendents to reduce construction costs to a minimum. In no book published hitherto, the authors declare, has the attempt been made to present both the methods of cost keeping and the principles of the science of engineering management, and, in this work, these two interrelated subjects are discussed as parts of one general subject. The Contents are: The Ten Laws of Management; Rules for Securing Minimum Cost; Piece Rate, Bonus and Other Systems of Payment; Measuring the Output of Workmen; Cost Keeping; Office Appliances and Methods; Bookkeeping for Small Contractors; Miscellaneous Cost Report Blanks and Systems of Cost Keeping; Index.

PAINTS FOR STEEL STRUCTURES.

By Houston Lowe, Assoc. Am. Soc. C. E. Fifth Edition. Cloth, 7½ x 5 in., 115 pp. New York, John Wiley & Sons; London, Chapman & Hall, Limited, 1910. $1.00.

The first edition of this little handbook was issued in 1899, and the preface of the present edition states that the author, who is himself a paint-maker, has, during the intervening ten years, continued his observations, experiments, and tests on a larger and more elaborate scale than ever before. It is further stated that many changes have been made, due largely to increasing knowledge of the problems presented. The Contents are: Introductions; Hypothesis; Paint and Painting; Steel; Rust; Cleaning; Liquids and Solids; Tests; Conclusion; Reference to Books; Index.

THE WATER SUPPLY, SEWERAGE AND PLUMBING OF MODERN CITY BUILDINGS.

By William Paul Gerhard. Cloth, 9 x 6 in., illus., 32 + 491 pp. New York, John Wiley & Sons; London, Chapman & Hall, Limited, 1910. $4.00 net.

This book is stated by the author to be the outgrowth of various lectures prepared for engineering societies and of essays written for technical journals. These articles and lectures have been revised and enlarged, new illustrations and many diagrams and tables added, and the entire subject brought up to date. The book deals with the subject from a practical standpoint, the preface states, being written by a practicing engineer who has devoted many years to the special topics under consideration. The chapters, while correlated, are, the author states, purposely written so that each one is complete in itself and may be used without reference to the others. The Contents are: Essential Features of the Hydraulic and Sanitary Engineering of Buildings; Sanitary Fixtures and Appliances; Advanced and Simplified Plumbing; Plumbing In Its Relation to Disease and Municipal Control of Plumbing; Domestic Water Supply; The Water Supply of Large Modern City Buildings; The Maintenance of Pipe Systems for Sewage, Gas and Water; Rules on Plumbing, Water-Supply and Sewerage, Chiefly for Hospital Buildings and Other Public Institutions; Appendix A, Definitions; Appendix B, Historical Sketch of the Development of the Art of the Drainage and Plumbing of Habitations; Appendix C, Specification Reminder; Appendix D, Explanation of Gerhard's Sewer Diagram; Appendix E, Conversion Diagrams; Alphabetical Index.

Gifts have also been received from the following:

Albany, N. Y.-Commr. of Public Works. 5 pam.
Am. Ry. Assoc. 1 pam.
Am. Soc. of Agri. Engrs. 1 pam.
Annan, C. L. 16 bound vol., 18 pam.
Assoc. of Am. Ry. Accounting Officers. 1 pam.
Beardsley, J. W. 1 pam.
Beer, W. 1 pam.
Belgium-Ministre des Chemins de Fer, Postes et Telegraphes. I bound vol.
Belzner, Theodore. 1 pam.
Berger, Bernt. 2 pam.
Binghamton, N. Y.-City Council. 5 bound vol.
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Editorial Review Co. 1 pam.
Engineers' Club of Toronto. 1 pam.
Ferrocarriles Nacionales de Mexico. 1 pam.
Goodrich, E. P. 1 bound vol.
Hartford, Conn.-Board of Water Commrs. 2 pam.
Hartford, Conn.-City Engr. 2 pam.
India-Irrig. Branch. 1 pam.
Indian Midland Ry. Co., Ltd. 1 pam.
Institution of Gas Engrs. 1 bound vol.
Inter. Bureau of Am. Republics. 2 pam.
Iron and Steel Inst. 1 bound vol.
Los Angeles, Cal.-Chf. Engr. of Los Angeles Aqueduct. 2 pam.

Manufacturers' Record Pub. Co. 1 pam.
Mass.-Cambridge Bridge Comm. 1 bound vol.
Mass. Inst. of Tech. 1 vol.
Minneapolis, Minn.-City Engr. 2 pam.
Missouri Pacific Ry. Co. 1 pam.
National Assoc. of Mfrs. 2 pam.
New Hampshire-State Forestry Comm. 4 bound vol., 3 pam.
New London, Conn.-Board of Water and Sewer Commrs. 1 pam.
New York City-Board of *City Record.* 2 bound vol.
New York City-Dept. of Parks. 1 pam.
Ohio-Bureau of Inspection and Supervision of Public Offices. 1 pam.
Panama R. R. Co. 1 pam.
Phillips, Asa E. 1 pam.
Poor's R. R. Manual Co. 1 bound vol.
Providence, R. I.-Dept. of Public Works. 1 pam.
Quebec Central Ry. Co. 4 pam.
Rutland, Vt.-City Clerk. 6 pam.
Scranton, Pa.-Chf. Engr., Dept., Public Works. 6 pam.
Sinaloa, Mexico-Seccion Meteorologica. 2 pam.
Société Anonyme Belge pour le Commerce du Haut-Congo. 2 pam.
Syracuse, N. Y.-City Engr. 1 pam.
Tasmanian-Govt. Rys. 1 pam.
Thomas, D. G. 1 pam.
U. S.-Bureau of Insular Affairs. 1 pam.
U. S.-Bureau of Standards. 7 pam.
U. S.-Bureau of Steam Eng. 1 pam.
U. S.-Bureau of Yards and Docks. 1 pam.
U. S.-Chf. of Engrs. 1 atlas, 1 pam.
U. S.-Commr. of Education. 1 bound vol.
U. S. Committee on River and Harbors. 17 pam.
U. S.-Geol. Survey. 4 pam.
U. S.-Lake Survey Office, 1 map.
U. S.-National Museum. 2 pam.
U. S.-Nautical Almanac Office. 1 bound vol., 1 pam.
U. S.-Office of Exper. Stations. 1 pam.
U. S.-Office of the Library and Naval War Records. 9 pam.
U. S.-Public Health and Marine Hospital Service. 2 pam.
U. S.-Secy. of the Senate. 6 vol.
U. S.-Weather Bureau. 1 bound vol.
Utah-State Engr. 1 pam.
Utica, N. Y.-City Engr. 4 pam.
Waddell, J. A. L. 4 pam.
Waterbury, Conn.-City Engr. 8 pam.
Whinery, S. 1 bound vol.
Williams, William F. 1 pam.
Woodworth, R. B. 1 pam.

BY PURCHASE.

Progressive Pennsylvania. A Record of the Remarkable Industrial Development of the Keystone State with Some Account of Its Early and Its Later Transportation Systems, Its Early Settlers, and Its Prominent Men. By James M. Swank. J. B. Lippincott Company, Philadelphia, 1908.

Modern Practice in Mining. Vol II. The Sinking of Shafts. By R. A. S. Redmayne. Longmans, Green and Co., London, New York, Bombay, and Calcutta, 1909.

Bauausführungen aus dem Ingenieurwesen. Dritter Band des Handbuches für Eisenbetonbau. Herausgegeben von F. von Emperger. Vol. 3. Wilhelm Ernst & Sohn, Berlin, 1908.

Bauausführungen aus dem Hochbau und Baugesetze. Vierter Band des Handbuches für Eisenbetonbau. Herausgegeben von F. von Emperger. 3 Vol. Wilhelm Ernst & Sohn, Berlin, 1909.

A Manual of Civil Engineering. By William John Macquorn Rankine. Twenty-third Edition, Revised by W. J. Millar. Charles Griffin and Company, Limited, London, 1907.

A Manual of Applied Mechanics. By William John Macquorn Rankine. Eighteenth Edition, Revised by W. J. Millar. Charles Griffin and Company, Limited, London, 1908.

Mitteilungen über Forschungsarbeiten auf dem Gebiete des Ingenieurwesens insbesondere aus den Laboratorien der technischen Hochschulen. Herausgegeben vom Verein Deutscher Ingenieure. Nos. 8-13, 17-41, 43-77. Julius Springer, Berlin, 1903-09.

SUMMARY OF ACCESSIONS

(From December 7th, 1909, to January 11th, 1910)

Donations (including 14 duplicates)	225
By purchase	64
Total	289

MEMBERSHIP

ADDITIONS

(December 8th, 1909, to January 11th, 1910)

MEMBERS		Date of Membership.
BOGGS, FRANK CRANSTOUN. Capt., Corps of Engrs., U. S. A.; Gen. Purchasing Officer, Isthmian Canal Comm., Washington, D. C.		Nov. 8, 1909
BROWN, NORMAN FREED. 427 Atlantic Ave., Pittsburg, Pa.	Assoc. M. M.	June 5, 1907 Nov. 30, 1909
CAMPEN, GEORGE LINDEN. Asst. City Engr., Omaha, Nebr.		Oct. 5, 1909
CAMPION, HORACE THOMAS. (Campion, McClellan Co.), 1218 Chestnut St., Philadelphia, Pa.		July 1, 1909
COOK, JOHN HENRY. Hydr. Engr., Society for Establishing Useful Manufactures, 158 Ellison St., Paterson, N. J.	Assoc. M. M.	May 4, 1898 Jan. 4, 1910
DAVIS, LYNN LEROY. U. S. Asst. Engr., 22 Ketchum Pl., Buffalo, N. Y.		Nov. 30, 1909
DOWNEY, ARCHIBALD STEWART. Cons. and Contr. Engr., 610 Bailey Bldg., Seattle, Wash.		Nov. 30, 1909
EMIG, JOHN WITMER. Western Representative for E. C. & R. M. Shankland, 720 E. & C. Bldg., Denver, Colo.		Oct. 5, 1909
FOX, HENRY. Chf. Engr., Maryland Dredging & Contr. Co., and Trust Clark Dredging Co. (Res., 2912 Evergreen Terrace), Baltimore, Md.		July 1, 1909
GOULD, HARRY MADERA. Vice-Pres. and Gen. Mgr., Foster-Creighton-Gould Co., Engrs. and Gen. Contrs., 3 Berry Blk., Nashville, Tenn.		Nov. 30, 1909
HOTCHKISS, LOUIS JENISON. Asst. Bridge Engr., C., B. & Q. R. R. Co., 209 Adams St., Chicago, Ill.		Nov. 30, 1909
MCCALLA, WILLIAM AUGUSTUS. Civ. and Municipal Engr., Decatur, Ala.		Nov. 30, 1909
MIDDLEBROOK, CHARLES TRINDER. Cons. Engr., 82 State St., Albany, N. Y.		Nov. 30, 1909
OGDEN, HENRY NEELY. Prof. of San. Eng., Cornell Univ., Ithaca, N. Y.	Jun. Assoc. M. M.	Oct. 3, 1893 Oct. 5, 1898 Nov. 30, 1909
REABURN, DE WITT LEE. Div. Engr., Los Angeles Aqueduct, Surrey, Cal.	Assoc. M. M.	April 6, 1904 Nov. 30, 1909
RIGHTER, ADDISON ALEXANDER. 519 The Rookery, Chicago, Ill.		Jan. 4, 1910
ROGERS, GEORGE HAMILTON. 5 East 42d St., New York City		July 1, 1909
SCHREIBER, JOHN MARTIN. Engr., M. of W., Public Service Ry. Corp., 7 Central Ave., Newark, N. J.	Assoc. M. M.	June 5, 1907 Nov. 30, 1909

MEMBERS (*Continued*).

		Date of Membership.
SHEPPARD, CHARLES ALFRED. 115 Purcell St., Edwardsville, Ill.		Nov. 30, 1909
STOWE, HAROLD CLAIR (Clarke & Stowe, Engrs. and Contrs.), 221 Greenpoint Ave., Brooklyn, N. Y.	Assoc. M. M.	April 7, 1897 Jan. 4, 1910
STRONG, CARLTON. Bellefield Dwellings, Pittsburg, Pa.		Jan. 4, 1910
THOMAS, CHESTER ASHLEY. Res. Engr., Yukon Gold Co., Dawson, Y. T., Canada		Nov. 8, 1909
THOMPSON, WILFORD ASHFORD. First Asst. City Engr.; Vice-Pres., East St. Louis Eng. Co. (Res., 1802 College Ave.), East St. Louis, Ill.	Jun. Assoc. M. M.	Oct. 1, 1901 Oct. 4, 1905 Nov. 30, 1909
WAUTERS, CARLOS. Avenida de Mayo 878, Buenos Aires, Argentine Republic		Oct. 5, 1909
WITMER, FRANCIS POTTS. Engr. in Chg. of Bridge Designing and Estimating, Am. Bridge Co., 30 Church St., New York City (Res., 32 Mulford St., East Orange, N. J.)		Nov. 30, 1909
WRENTMORE, CLARENCE GEORGE. Care, Bureau of Public Works, Manila, Philippine Islands	Assoc. M. M.	April 5, 1905 Oct. 5, 1909

ASSOCIATE MEMBERS

BAKE, WILLIAM SIBSON. Asst. Engr., G. R. & I. Ry., Grand Rapids, Mich.		Jan. 4, 1910
BARTELL, MAX JOHN. Asst. Engr., City Engr.'s Office, Hewes Bldg., San Francisco, Cal.	Jun. Assoc. M.	May 1, 1906 Oct. 5, 1909
BLAAUW, GEERT. Asst. Engr. with F. S. Pearson, 25 Broad St., 20th Floor, New York City		Nov. 30, 1909
BLACKMORE, GEORGE GLOVER. 35 Jackson Ave., Long Island City, N. Y.		Nov. 30, 1909
BROWER, IRVING CLINTON. Asst. Engr., Chic. & N. W. Ry., Care, E. C. Carter, Chf. Engr., Chicago, Ill.		Nov. 30, 1909
BROWN, BURTIS SCOTT. Structural Engr., 161 Devonshire St., Room 709, Boston, Mass.		Oct. 5, 1909
BUTLER, ALFRED DICKEY. Asst. City Engr., Spokane, Wash.		Oct. 5, 1909
DAVENPORT, JAMES WATSON. Res. Engr., Lake View Traction Co., North Memphis Saving Bank Bldg., Memphis, Tenn.		Nov. 30, 1909
DAVOUD, VAHRAM YETTVART. Elec. Engr., The Telluride Power Co., Provo, Utah		July 1, 1909
FARLEY, WILLIAM SANBORN. Gen. Contr. (Scott & Farley), 48 Bacon Bldg., Oakland, Cal.		Nov. 8, 1909
FARRIN, JAMES MOORE. Engr. of Bridges and Bldgs., Cuba R. R., Camaguey, Cuba		Nov. 30, 1909

ASSOCIATE MEMBERS (*Continued*).

		Date of Membership.
HADSALL, JOSEPH CANBY. Wheatland, Wyo.		Nov. 8, 1909
HAYNES, CLAUDE SANFORD. 575 Dean St., Brooklyn, N. Y.		Jan. 4, 1910
HOVEY, RAY PALMER. With Minneapolis Steel & Machinery Co., 324 Dooley Blk., Salt Lake City, Utah	Jun. Assoc. M.	Jan. 2, 1906 Nov. 8, 1909
HUTCHINS, EDWARD. East Walpole, Mass.	Jun. Assoc. M.	June 6, 1905 Jan. 4, 1910
JAMES, ALFRED RANDOLPH. Chf. Draftsman, Pac. Div., Isthmian Canal Comm., Corozal, Canal Zone, Panama		Nov. 8, 1909
JEWETT, THOMAS EDWARD. Vice-Pres., H. L. Stevens & Co., 802 Texas Ave., Houston, Tex.		Nov. 30, 1909
JONES, WALTER ALPHEUS. Chf. Engr., Titusville Northern R. R., Box 270, Titusville, Pa.		Nov. 30, 1909
KASTENHUBER, EDWIN GUSTAV, JR. P. O. Box 677, Bordentown, N. J.		July 1, 1909
MITCHELL, LESTER HALE. Care, U. S. Reclamation Service, Glendive, Mont.		Oct. 5, 1909
PEOTTER, REUBEN SYLVESTER. Massena, N. Y.		Nov. 30, 1909
PULLAR, WILLIAM MURRAY. "St. Kitts," Essendon, Victoria, Australia		Aug. 31, 1909
SCHRADER, FREDERICK ADOLPH. Engr. in Chg., Foundation Dept., John Monks & Sons, 82 Beaver St., New York City		Jan. 4, 1910
SHELDON, PAUL. Secy. and Treas., Buck & Sheldon, Inc., 36 Pearl St., Hartford, Conn.		Oct. 5, 1909
SHELMIRE, ROBERT WARREN. Draftsman, Wheeling & Lake Erie R. R., Cleveland, Ohio		Nov. 30, 1909
SISSON, GEORGE ARTHUR. Junior Engr., U. S. Engr. Dept., Fort Stevens, Ore.	Jun. Assoc. M.	April 30, 1907 Oct. 5, 1909
TIBBETTS, FRANK LESLIE. 19 Congress St., Room 82, Boston, Mass.		Jan. 4, 1910
VERNON, STEPHEN BARKER. Designing Engr., Syracuse Intercepting Sewer Board, 112 Court House, Syracuse, N. Y.		Jan. 4, 1910
WATKINS, GUY ANDERSON. (Dickinson, Kingsley & Watkins), Southern Trust Bldg., Little Rock, Ark.	Jun. Assoc. M.	Jan. 3, 1907 Nov. 8, 1909
WESCOTT, JAY VARNUM. 1775 Old Colony Bldg., Chicago, Ill.		Nov. 30, 1909

ASSOCIATE

HARTMANN, ERNEST FREDERICK. Pres., Carbolineum Wood Preserving Co., 182 Franklin St., New York City		Jan. 4, 1910

JUNIORS	Date of Membership.
BILLWILLER, ERNEST OSWALD. 167 Washington Ave., San José, Cal	Nov. 8, 1909
BROOKS, JOHN NIXON. 240 W. State St., Trenton, N. J.	Nov. 8, 1909
CATER, WALTER DAY. Civ. Engr. for the Am. Cement Engr. Co., Yorktown, Va	Nov. 30, 1909
EDGERTON, GLEN EDGAR. 1810 I St., N. W., Washington, D. C	Nov. 8, 1909
HAZEN, RICHARD. 209 State St., Portland, Me	Nov. 8, 1909
KING, EDMUND GEDDES. Pottsville, Pa	Nov. 8, 1909
MILLER, HUGH. 93 Main St., Potsdam, N. Y	Nov. 30, 1909
MORRISON, CHRISTOPHER GEORGE. Asst. Engr., Dist. No. 8, Bureau of Public Works, Guinobatan, Albay, Manila, Philippine Islands	Oct. 5, 1909
NEUHARDT, EDWIN. Instrumentman, City Engr.'s Office, City Hall, Memphis, Tenn	Nov. 8, 1909
SHERMAN, ARTHUR LOUIS. Asst. Engr., Board of Water Supply of New York, Y. M. C. A., White Plains, N. Y	Jan. 4, 1910
STEWART, CHARLES SUMNER. 5757 Drexel Ave., Chicago, Ill	Nov. 30, 1909
SWEETLAND, HAROLD ANTHONY. 9 Orchard Ave., Providence, R. I	Oct. 5, 1909
VEATCH, NATHAN THOMAS, JR. Res. Engr. for The J. S. Worley Co., Cons. Engrs., 206 Reliance Bldg., Kansas City, Mo	Nov. 8, 1909

RESIGNATIONS

MEMBERS	Date of Resignation.
CURRY, CHARLES WHITE	Dec. 31, 1909
MAYNE, CHARLES	Dec. 31, 1909
PARKER, ANDREW MCCLEAN	Dec. 31, 1909
SYMONS, THOMAS WILLIAM	Dec. 31, 1909
TWYMAN, AARON	Dec. 31, 1909
WAITT, ARTHUR MANNING	Dec. 31, 1909
ASSOCIATE MEMBERS	
CONROW, HERMAN	Dec. 31, 1909
TIERNAN, AUSTIN KING	Dec. 31, 1909
TOWSON, MORRIS SHERMAN	Dec. 31, 1909
ASSOCIATES	
BERTHELET, JOSEPH R	Dec. 31, 1909
COOPER, WILLIAM HILL	Dec. 31, 1909

JUNIORS	Date of Resignation.
Bunker, Paul Delmont	Dec. 31, 1909
Carpenter, John Earl	Dec. 31, 1909
English, Charles Clement	Dec. 31, 1909
Gugerty, Edward Joseph	Dec. 31, 1909
Mercer, Charles Douglas	Dec. 31, 1909
Ratcliff, Walter Harris	Dec. 31, 1909
Seabury, Arthur Gray	Dec. 31, 1909
Wolff, Max William	Dec. 31, 1909

DEATHS

Church, George Earl. Elected Member, November 2d, 1887; died January 5th, 1910.

d'Invilliers, Camille Stanislaus. Elected Member, January 4th, 1888; died January 2d, 1910.

Dudley, Charles Benjamin. Elected Member, March 2d, 1892; died December 21st, 1909.

Metcalf, William (*Past-President*). Elected Member, July 2d, 1873; died December 5th, 1909.

Rhys-Roberts, Edmund Alyth. Elected Associate Member, November 3d, 1897; died October 5th, 1909.

Starr, William Wright. Elected Member, May 1st, 1907; date of death unknown.

Van der Hoek, Jacobus. Elected Member, April 7th, 1897; died December 22d, 1909.

Total Membership of the Society, January 11th, 1910, 5 299.

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST

(December 7th, 1909, to January 10th, 1910)

NOTE.—*This list is published for the purpose of placing before the members of the Society, the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS

In the subjoined list of articles, references are given by the number prefixed to each journal in this list:

(1) *Journal*, Assoc. Eng. Soc., 31 Milk St., Boston, Mass., 30c.
(2) *Proceedings*, Engrs. Club of Phila., 1317 Spruce St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Engrs., Monadnock Blk., Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Canada.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech., Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Inst., Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 25c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 25c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c.
(14) *Engineering Record*, New York City, 12c.
(15) *Railway Age Gazette*, New York City, 15c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Electric Railway Journal*, New York City, 10c.
(18) *Railway and Engineering Review*, Chicago, Ill., 10c.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England, 25c.
(22) *Iron and Coal Trades Review*, London, England, 25c.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gas Light Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World*, New York City, 10c.
(28) *Journal*, New England Water-Works Assoc., Boston, Mass., $1.
(29) *Journal*, Royal Society of Arts, London, England, 15c.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales* de l'Assoc. des Ing. Sortis des Ecoles Spéciales de Gand, Brussels, Belgium.
(32) *Mémoires et Compte Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economiques des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(37) *Revue de Mécanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Proceedings*, Am. Inst. Elec. Engrs., New York City, 50c.
(43) *Annales des Pontes et Chaussées*, Paris, France.
(44) *Journal*. Military Service Institution, Governors Island, New York Harbor, 50c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 8c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift*, Verein Deutscher Ingenieure, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Düsseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift*, Oesterreichischer Ingenieur und Architekten Verein, Vienna, Austria.
(54) *Transactions*, Am. Soc. C. E., New York City, $4.
(55) *Transactions*, Am. Soc. M. E., New York City, $10.
(56) *Transactions*, Am. Inst. Min. Engrs., New York City, $5.

(57) *Colliery Guardian,* London, England.
(58) *Proceedings,* Engrs.' Soc. W. Pa., 803 Fulton Bldg., Pittsburg, Pa., 50c.
(59) *Transactions,* Mining Inst. of Scotland, London and Newcastle-upon-Tyne, England.
(60) *Municipal Engineering,* Indianapolis, Ind., 25c.
(61) *Proceedings,* Western Railway Club, 225 Dearborn St., Chicago, Ill., 25c.
(62) *Industrial World,* 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings,* Inst. C. E., London, England.
(64) *Power,* New York City, 20c.
(65) *Official Proceedings,* New York Railroad Club, Brooklyn, N. Y., 15c.
(66) *Journal of Gas Lighting,* London, England, 15c.
(67) *Cement and Engineering News,* Chicago, Ill., 25c.
(68) *Mining Journal,* London, England.
(70) *Engineering Review,* New York City, 10c.
(71) *Journal,* Iron and Steel Inst., London, England.
(71*a*) *Carnegie Scholarship Memoirs,* Iron and Steel Inst., London, England.
(73) *Electrician,* London, England, 18c.
(74) *Transactions,* Inst. of Min. and Metal., London, England.
(75) *Proceedings,* Inst. of Mech. Engrs., London, England.
(76) *Brick,* Chicago, Ill., 10c.
(77) *Journal,* Inst. Elec. Engrs., London, England.
(78) *Beton und Eisen,* Vienna, Austria.
(79) *Forscherarbeiten,* Vienna, Austria.
(80) *Tonindustrie Zeitung,* Berlin, Germany.
(81) *Zeitschrift für Architektur und Ingenieurwesen,* Wiesbaden, Germany.
(83) *Progressive Age,* New York City, 15c.
(84) *Le Ciment,* Paris, France.
(85) *Proceedings,* Am. Ry. Eng. and M. of W. Assoc., Chicago, Ill.
(86) *Engineering-Contracting,* Chicago, Ill., 10c.
(87) *Roadmaster and Foreman,* Chicago, Ill., 10c.
(88) *Bulletin* of the International Ry. Congress Assoc., Brussels, Belgium.
(89) *Proceedings,* Am. Soc. for Testing Materials, Philadelphia, Pa.
(90) *Transactions,* Inst. of Naval Archts., London, England.
(91) *Transactions,* Soc. Naval Archts. and Marine Engrs., New York City.
(92) *Bulletin,* Soc. d'Encouragement pour l'Industrie Nationale, Paris, France.
(93) *Revue de Métallurgie,* Paris, France, 4 fr. 50.
(94) *The Boiler Maker,* New York City, 10c.
(95) *International Marine Engineering,* New York City, 20c.
(96) *Canadian Engineer,* Toronto, Canada, 15c.
(97) *Turbine,* Berlin, Germany, 1 Mark.
(98) *Journal,* Engrs. Soc. Pa., 219 Market St., Harrisburg, Pa., 30c.
(99) *Proceedings,* Am. Soc. of Municipal Improvements, New York City, $1.
(100) *Professional Memoirs,* Corps of Engrs. U. S. A., Washington, D. C., $1.25.
(101) *Metal Worker,* New York City, 10c.

LIST OF ARTICLES

Bridges.

The Substructure of the Passyunk Bridge.* Henry H. Quimby. (2) Oct.
The Mulberry Street Viaduct, Harrisburg, Pa.* John E. Allen and Benj. G. Love. (2) Oct.
Concrete Bridges.* Daniel B. Luten. (98) Oct.
Plans and Specifications for Reinforced Concrete Arches. George H. Dunham. (98) Oct.
The Construction of a Four-Track Truss Bridge with Solid Floor; Chicago and Oak Park Elevated Ry.* (13) Dec. 9.
First Street Bridge, Brandon, Man.* R. E. Speakman, M. Can. Soc. C. E. (96) Dec. 10.
Bridge Inspection Disclosures. (14) Dec. 11.
Suspension Bridge of 600-Ft. Span Across the Culebra Cut of the Panama Canal.* A. S. Zinn, M. Am. Soc. C. E. (13) Dec. 16.
The Fabrication of Heavy Current Drawbridge Girders.* (14) Dec. 18.
A Flat Slab Reinforced-Concrete Street Railway Bridge, St. Paul, Minn.* (13) Dec. 23.
Foundation Work for New Bridge of the P. & P. U. Ry., at Peoria.* (18) Dec. 25.
The Delaware River Concrete Bridge, Slateford-Hopatcong Cut-off; Delaware, Lackawanna & Western R. R.* (13) Dec. 30.
The Construction of the Rocky River Bridge.* (14) Jan. 1.
The Construction of the Substructure of the McKinley Bridge across the Mississippi River at St. Louis, Mo.* F. E. Washburn. (13) Jan. 6.
A New Moment Table (Railroad Bridges).* C. R. Young, A. M. Can. Soc. C. E. (96) Jan. 7.

*Illustrated.

Bridges—(Continued).

Calculation of Stresses in Suspension Bridges.* Ralph Modjeski. (App. to report on Manhattan Bridge.) (14) Jan. 8.
Note sur le Calcul des Bow-Strings Continus Application à un Viaduc en Béton Armé.* Henry Lossier. (33) Nov. 27.
Note sur l'Exécution des Travaux d'Elargissement du Viaduc de St.-Florent au Moyen d'Encorbellements en Ciment Armé.* M. Verdeaux. (38) Dec.
Pont Suspendu Rigide de la Cassagne, Système Gisclard; Chemin de Fer Electrique de Villefranche à Bourg-Madame (Pyrénées-Orientales.)* Henri Toulet. (35) Dec.
Die Parkgassenbrücke in Temesvar (Ungarn).* Viktor Mihailich. (78) Nov. 23.
Schwebefähre über die Oste bei Osten.* (51) Serial beginning Dec. 4.

Electrical.

Recent Improvements in Incandescent Lamps.* F. W. Wilcox. (2) Oct.
The Testing of Steel for Magnetic Circuits.* H. Clyde Snook. (2) Oct.
Some of the Laws Concerning Voltaic Cells.* Edward H. Landis. (3) Dec.
Wireless Telegraphy Plant at the Eiffel Tower.* Louis Dubois. (73) Dec. 3.
Shop Testing of Direct and Alternating-Current Machinery. J. W. Rogers. (Paper read before the Rugby Eng. Soc.) (47) Dec. 3; (12) Dec. 17.
Factors Affecting the Design of Self-Excited, Single-Phase, Shunt Induction Motors.* Val. V. Fynn. (27) Serial beginning Dec. 9.
The Use of Iron in Dynamometer Wattmeters.* Charles V. Drysdale. (73) Dec. 10.
Majorana's Wireless Telephone.* (19) Dec. 11.
Protection of Underground Pipes from Electrolysis. Albert F. Ganz. (Paper read before the Amer. Gas Inst.) (83) Dec. 15.
Mercadier's System of Telegraphy.* (73) Dec. 17.
Marconi Wireless Telegraphy.* G. Marconi. (12) Dec. 17.
The Distribution and Application of Electric Power.* J. S. Peck. (Paper read before the Manchester Assoc. of Engrs.) (47) Serial beginning Dec. 17.
Vector Diagrams of Polyphase Windings.* M. V. Ayres. (27) Dec. 23.
Madison River Hydroelectric Development.* (27) Dec. 23.
Heavy-Current Resistances of Small Inductance. E. Orlich. (Abstract from *Zeit. für Instrumentenkunde.*) (73) Dec. 24.
Modern Fac-Simile Telegraphs.* Alfred Gradenwitz. (19) Dec. 25.
Generating Station of the Lehigh Coal & Navigation Company.* (27) Dec. 30.
Some Phases of Transformer Regulation.* W. A. Hillebrand and S. B. Charters, Jr. (42) Jan.
The Rignoux-Fournier System of Television.* Fernand Honoré. (46) Jan. 1.
Comparative Methods and Cost of Underground Conduit Construction.* Clarence Mayer. (86) Jan. 5.
New Theater, New York City; Electrical Equipment and Illumination of the Most Artistic Theater in America.* N. M. Schoonmaker. (27) Jan. 6.
Northern Connecticut Light & Power Co.* (27) Jan. 6.
Electricity on the Farm.* (27) Jan. 6.

Marine.

The Design and Performance of Curtis Marine Turbines.* A. P. Chalkley. (11) Dec. 3.
The Lancashire and Yorkshire Railway Company's Turbine Steamers.* (11) Dec. 3.
Transmission Gear for Marine Turbines.* (11) Dec. 3.
The Six-Masted Schooner *Wyoming*.* (95) Jan.
The Influence of the Depth of Water on the Resistance and Speed of High-Speed Torpedo Craft.* (95) Jan.
Twin-Screw Steamer for Submarine Mine Service.* Harry L. Fuller and V. R. Marsden. (95) Jan.
The U. S. Colliers *Mars, Vulcan* and *Hector*.* (95) Jan.
Design for Concrete Dry-Dock at Pearl Harbor, Hawaii, for the United States Navy.* R. E. Bakenhus. (13) Dec. 9.
Dipper Dredge for Excavating Rock, Montreal Water-Works.* (86) Dec. 15.
The Melville and Macalpine Speed Reduction Gear for Marine Steam Turbines.* (13) Dec. 30.
The Dredges *Leviathan* and *Coronation*. H. Leroy Potter. (100) Jan.
The Dredge *Leviathan*. Horace Lee Washington. (100) Jan.
A Large Wood and Steel Floating Dry-Dock.* (14) Jan. 8.
Le Cargo-Boat *Pallon* à Déchargement par Transporteurs à Courroies.* (33) Dec. 18.

Mechanical.

Mechanical Transshipment of Railway and Water-Borne Freight, with Special Reference to the Port of New York.* H. McL. Harding. (65) Dec.
The Gains of Down-Draft over Up-Draft Kilns and Why. Butler. (Abstract of paper read before the Brick Mfrs. Assoc.) (76) Dec.

*Illustrated.

Mechanical—(Continued).

Development of an Irregular Pipe Connection by the Method of Tangent and Crossing Planes.* I. J. Haddon. (94) Dec.
The Power Developed by Windmills. Wm. Paul Gerhard, M. Am. Mech. Engrs. (70) Dec.
Improvements in Resilient Wheels for Vehicles.* R. Clere Parsons. (29) Dec. 3.
A 6 000 Horse-Power Dynamometer.* (12) Dec. 3.
Burning Natural Gas as a Boiler Fuel. David Moffat Myers. (64) Dec. 7.
A Tarless Oil-Gas Producer.* A. B. Davis. (Paper read before the Ohio Soc. of Mech. and Elec. Steam Engrs.) (13) Dec. 9.
Producer Gas Plant Practice.* Michael Chapman, A. M. I. E. E. (Paper read before the Engrs.' Club of Toronto.) (96) Dec. 10.
Apparatus for Testing Aeroplane Models.* C. E. Larned, M. I. Mech. E., and R. O. Boswell. (11) Dec. 10.
A Method of Calculating Steam-Turbines.* Rateau. (Tr. of paper read before the Assoc. Tech. Maritime.) (11) Dec. 10.
Gary: The Largest and Most Modern Steel Works in Existence.* (46) Dec. 11.
The Interborough Low-Pressure Turbine.* Fred L. Johnson. (64) Dec. 14.
Some Recollections of Soho Foundry, its Men and Methods.* Charles H. Wall, M. I. Mech. E. (12) Dec. 17.
The Barometric Condenser Built by the Mesta Machine Co.* (62) Dec. 20.
Preventable Losses by the Municipal Boiler Plants of New York City. (13) Dec. 23.
The Design and Construction of Aeroplanes.* J. P. Chittenden and L. H. Robinson. (Paper read before the Rugby Eng. Soc.) (47) Dec. 24.
The Noble Electric Steel Co.'s Plant.* Dorsey A. Lyon. (Abstract of paper read before the Amer. Electrochemical Soc.) (73) Dec. 24.
The Simplex By-Product Coke Oven; Installation of 100 Ovens at the Devonshire Works of the Staveley Company, Limited, near Chesterfield.* (57) Dec. 24.
Aeronautics.* Charles Cyril Turner. (29) Serial beginning Dec. 24.
Cost of Making Cement in England. Harry Horsburgh, Assoc. M. Inst. C. E. (Abstract of paper read before the Jun. Inst. C. E.) (14) Dec. 25.
The Wonderful Gyrostat, its Principles and Applications.* Horace B. M'Cabe. (From *American Machinist.*) (19) Dec. 25.
Air Gas Lighting. Herbert A. Carter. (66) Dec. 28.
The Cost of Producing Crushed Stone in Boston, Mass., by City Operated Crushing Plants. (86) Dec. 29.
Gas Producer Central Station at Aberdeen, South Dakota.* (27) Dec. 30.
75-Ton Floating Crane.* (96) Dec. 31.
Making Steam with Mixed Fuel.* Arthur S. Mann. (9) Jan.
The Development of the Aeroplane.* Henry Harrison Suplee. (10) Jan.
The Design, Construction and Operation of High-Lift Centrifugal Pumps.* Franz zur Nedden. (9) Jan.
On the Number of Courses in a Boiler Shell.* (94) Jan.
The Wright Flyer and its Possible Uses in War.* F. E. Humphreys. (100) Jan.
Sewalls Point Coal Pier.* F. F. Harrington. (Abstract of paper read before the Appalachian Eng. Assoc.) (45) Jan.
Report of Committee on Benzol Enrichment (Amer. Gas. Inst.).* (83) Jan. 1; (24) Jan. 3.
Condensing Plant of Novel Design.* Frederick Ray. (64) Jan. 4.
A Rational Method of Determining the Principal Dimensions of Water-Turbine Runners.* S. J. Zowski. (13) Jan. 6.
Gas-Engine Alternators in Parallel. Warren H. Miller. (27) Jan. 6.
Power Development for the Scranton Shops.* (15) Jan. 7.
General Shops of the Sud-Pacifico de Mexico at Empalme.* (15) Jan. 7.
Excavateurs, Système Orenstein et Koppel, Employés aux Travaux du Port de Séville.* (33) Nov. 27.
Concours de Véhicules Automobiles Industriels (Versailles 15 octobre-15 novembre 1909).* E. Girardault. (33) Nov. 27.
Notes sur la Théorie des Engrenages.* A.-R. Garnier. (37) Serial beginning Nov. 30.
Récupération de la Chaleur Dégagée dans la Compression de l'Air et son Application aux Services de Traction et aux Transports de Force.* (34) Dec.
Transport des Minerais de Fer du Canigou à Port-Vendres (Pyrénées-Orientales).* J.-E. Giraud. (33) Dec. 4.
Le Controle Chimique de la Combustion dans les Foyers Industriels.* E. Grandmougin. (33) Dec. 4.
Le Dernier Type de Dirigeable Rigide *Zeppelin.** (33) Dec. 11.
Les Grandes Acières de l'Indiana Steel Co. à Gary (Indiana, E.-U.).* F. Hofer. (33) Dec. 11.
Outillage pour la Manutention du Charbon dans le Port de Gênes.* (33) Dec. 25.
Excavateurs à Commande Electrique.* (33) Dec. 18.

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*Illustrated.

Mechanical—(Continued).

Berechnung von Radscheiben.* Huldreich Keller. (97) Dec. 5.
Der Grossgasmaschinenbau in Amerika. Rieppel. (48) Serial beginning Dec. 11.
Pumpen und Kompressoren mit Einer Neuen Ventilkonstruktion.* O. Klepal. (48) Dec. 18.
Untersuchung der Wirkungsweise der Regelungsberichtigung bei der Regelung von Turbinen. A. Renard. (97) Serial beginning Dec. 20.

Metallurgical.

The Special Steels in Theory and Practice. Walter Giesen. (71*a*) Vol. I.
The Preparation of Carbon-Free Ferro-Manganese (Further Experiments).* E. A. Wraight. (71*a*) Vol. I.
Gases Occluded in Steel.* Thomas Baker. (71*a*) Vol. I.
Recent Progress in Open Hearth Steel Practice.* Bradley Stoughton. (3) Dec.
Smelting Plant of the Butte Reduction Works.* A. H. Wethey. (16) Dec. 11.
Oil-Fired Reverberatory Furnace.* R. L. Herrick. (45) Jan.
The Malm Dry Chlorination Process.* R. L. Herrick. (45) Jan.
A New Process in Iron Metallurgy; Slow-Rusting Iron Produced in the Open-Hearth Furnace. (13) Jan. 6.

Military.

Sights for Small Arms and Machine-Guns.* (11) Dec. 3.

Mining.

Winding Engine Design.* G. James Wells, Assoc. M. Inst. C. E. (Astract of paper read before the Manchester Assoc. of Engrs.) (57) Serial beginning Dec. 10; (22) Serial beginning Dec. 3.
Record of an Experimental Blast with Some Data on Cost.* (86) Dec. 15.
A Drilling Auger for Prospecting for Coal above Water Level.* Baird Halberstadt. (Abstract of paper read before the Appalachian Eng. Assoc.) (13) Dec. 16.
Sinking the John Shaft at Hamsterley Colliery through Sand and Gravel by Means of Underhanging Tubbing. John Cummings. (Paper read before the North of Eng. Inst. of Min. and Mech. Engrs.) (22) Dec. 17.
The Effect of Sprayers in the Main Roads of Collieries.* T. L. Elwen. (Abstract of paper read before the North of Eng. Inst. of Min. and Mech. Engrs.) (22) Dec. 17.
Mechanical Haulage in Mines. (Abstract of Report of a Committee to the Royal Comm. on Mines.) (47) Serial beginning Dec. 17.
Discussion of Explosives in Coal Mines.* Frank F. Morris. (16) Dec. 18.
Hydraulic Landing Chair.* M. Clapier. (Abstract from *Compt. Rend.*) (16) Dec. 18.
San Ygnacio Mine and Mill, Chihuahua, Mex.* Oreste Peragallo. (16) Dec. 25.
Mines of the Granby Consolidated, Phœnix, B. C.* Roy Hutchins Allen. (16) Dec. 25.
The Concentration of Magnetic Iron Ores.* N. V. Hansell. (9) Jan.
Mexican "Planilla" Concentrator.* H. J. Baron. (45) Jan.
Skip-Changing Devices at Butte. R. L. Herrick. (45) Jan.
Electrostatic Zinc Separation.* Leroy A. Palmer. (45) Jan.
The Center Star Group of Mines, Rossland, B. C.* Roy Hutchins Allen. (16) Jan. 1.
Data on the Storage and Handling of Explosives.* (Abstract from *Bulletin* U. S. Geol. Surv.) (86) Jan. 5.
Concentrating the Lean Ores of the Mesaba Range.* (20) Jan. 6.

Miscellaneous.

The Cost of Hauling with Traction Engines and Dump Wagons as Compared with Hauling with Horses.* (Abstract of report by the Construction Service Co.) (86) Dec. 8.
Moving Earth with Elevating Graders and Dump Wagons. (14) Dec. 11.

Municipal.

Methods and Cost of Sprinkling Road Surfaces with Oil.* W. A. Gillette. (86) Dec. 8.
Specifications of the New York State Highway Department for Bituminous Macadam and Characteristics Required of the Bituminous Materials. (86) Dec. 8.
Reconstruction of the Washington Street Tunnel, Chicago.* (14) Dec. 11.
Costs of Various Kinds of Municipal and Sanitary Work at Panama. (86) Dec. 15.
Cost of Patching Asphalt Pavement, using a Small Repair Plant. (86) Dec. 15.
Standard Specifications of the New York State Highway Commission for Brick Pavement.* (86) Dec. 15.

*Illustrated.

Municipal—(Continued).

Standard Details of the New York State Highway Department for State and County Roads.* (86) Dec. 15.
Extracts from Papers before the British Road Conference of 1909.* (13) Dec. 16.
Control of Workmanship on Asphalt Pavements. L. Kirschbraum. (From the *Michigan Technic.*) (96) Serial beginning Dec. 17.
The Possibilities of Portland Cement as a Road Material. Logan W. Page. (Paper read before the Assoc. of Amer. Portland Cement Mfrs.) (13) Dec. 23; (14) Dec. 25.
Cost of Road Treatment with Oil and other Dust Preventives at Washington, D. C. (86) Dec. 29.
Municipal Park Improvement.* (96) Dec. 31.
Town Scavenging and Refuse Disposal; Street Cleaning. Hugh S. Watson, A. M. I. C. E. (60) Jan.
Tests of Street Flushing Machines, New York City. (14) Jan. 8.

Railroads.

Electrification of Railroads. Frederick Darlington. (98) Oct.
Electrification of Chicago Railways. C. A. Seley. (61) Nov.
Transportation of Dangerous Articles.* B. W. Dunn. (61) Nov.
H-8-b Class Freight Engines: Pennsylvania Railroad.* (21) Dec.
Management of Locomotive Superheaters.* John Williams and Jas. T. Hodgson. (21) Dec.
Report on the Question of Perishable Goods. (Subject for discussion at the 8th Sess. of the Ry. Cong.)* J. M. Culp. (88) Dec.
Report on the Question of Motor Car Services. (Subject for discussion at the 8th Sess. of the Ry. Cong.)* J. C. Inglis. (88) Dec.
Note on the Metal Screw Bushes for Strengthening Rail Fastenings. P. de Varine. (88) Dec.
Methods Employed for Working Electric Railways.* E. C. Zehme. (88) Dec.
Electric Traction Conditions in the Argentine Republic.* A. C. Kelly, Assoc. M. Inst. C. E. (11) Dec. 3.
Original Cost and Cost of Reproduction of the Great Northern Railway (768 Miles) in the State of Washington. (86) Dec. 8.
Padova-Fusina Single-Phase Railway.* Mario Stoppoloni. (27) Dec. 9.
Consolidation Locomotive for the Southern Utah Railroad.* (15) Dec. 10.
Switch Adjustment. W. H. Arkenburgh. (15) Dec. 10.
Pacific Locomotive for the Western Railway of France.* (15) Dec. 10.
Chicago's Sixty Miles of Freight Subway. (46) Dec. 11.
Cost of Constructing the Miraflores Tunnel on the Panama R. R.* (86) Dec. 15.
Locomotive Proportions and Power.* G. James Wells, Assoc. M. Inst. C. E. (12) Serial beginning Dec. 17.
Compound Engines. R. M. Deeley, M. Inst. C. E. (12) Dec. 17.
The Hybrid Mallet Compound on the Great Northern Ry.* (18) Dec. 18; (15) Dec. 17.
Rail Creeping on Wet Sub-Grade.* (15) Dec. 17.
Railway Depreciation Accounts. C. I. Sturgis. (Abstract of paper read before the National Assoc. of Ry. Commrs.) (17) Dec. 18.
Side and Center Bearings of a Car.* A. Stucki. (Abstract of paper read before the Ry. Club of Pittsburg.) (18) Dec. 18.
Railway Terminals and Their Relation to City Planning. Frederic A. Delano. (Paper read before the Amer. Inst. of Archts.) (14) Dec. 18; (15) Dec. 24.
Subaqueous Section of the Detroit River Tunnel.* (14) Serial beginning Dec. 18.
The Bergen Hill Four-Track Tunnels, Erie Railroad.* (14) Dec. 18.
The Cost of Overhead-Trolley Systems. A. D. Williams, Jr. (14) Dec. 23.
Tunnel Failures and Repairs on the Eastern Railway of France.* (13) Dec. 23.
Two Recent Developments in Car Ventilation.* (13) Dec. 23.
The Bergen and Christiania Railway.* (11) Dec. 24.
Accumulator Railway Cars for the Prussian State Railways.* C. Van Langendonck. (15) Dec. 24.
Kendrick Tie Finishing and Screw Pike Driving Machine.* (15) Dec. 24.
Railway Signaling. Henry G. Prout. (From *Harper's Weekly.*) (15) Dec. 24.
The Oranienburg Experimental Line of the Prussian Government Railways.* (17) Dec. 25.
Comparison of Gasoline Car, Single-Phase and Steam Locomotive Costs.* W. E. Harrington. (17) Dec. 25.
Application of Motor Trucks to Railroad Service. T. V. Buckwalter. (Abstract of paper read before the Eng. Club of Altoona.) (18) Dec. 25.
Some Retaining Wall Construction in Connection with the Chicago & Northwestern Ry. Track Elevation Work in Chicago.* (86) Dec. 29.
Multiple Unit Circuits for Single-Phase Trains.* Ralph W. Krass. (27) Dec. 30.
A Comparative Test of Electric and Acetylene Headlights on Locomotives. Henry L. Gray, Assoc. M. Am. Soc. C. E. (13) Dec. 30.
An Electrically Operated Plane.* Alfred Gradenwitz. (45) Jan.

*Illustrated.

Railroads—(Continued).

On the Space Economy of the Single-Phase Series Motor.* Wm. S. Franklin and Stanley S. Seyfert. (42) Jan.
Locomotive Terminals.* (25) Serial beginning Jan.
Fuel Economy on Testing Plants and Railroads.* H. H. Vaughan. (Paper read before the Western Canadian Ry. Club.) (25) Jan.
The St. Louis Water Works Railway. Charles Claude Casey. (60) Jan.
The Thamshavn-Lokken Single-Phase Electric Road.* (18) Jan. 1.
Block Signal Installations C., R. I. & P. Ry.* (18) Jan. 1.
Express Passenger Locomotives; Paris, Lyons and Mediterranean Railway.* Ernest Graham. (15) Jan. 7.
Railroad Location.* W. G. Swan. (96) Serial beginning Jan. 7.
Les Loqueteaux Automatiques de Sureté pour Portières de Chemins de Fer.* Ch. Dantin. (33) Nov. 27.
Note sur Quelques Ateliérs de Reparation et de Construction de Locomotives en Amériques (1908).* J. Desgeans et F. Houlet. (38) Dec.
Locomotive Electrique à Adhérence et à Crémaillere de la Ligne Montreux-Glion (Suisse).* (33) Dec. 4.
Etude d'une Commande par Bielles pour Locomotives Electriques de Trains de Marchandises.* Curt Heilfron. (33) Dec. 25.
Die 5/5-Gekuppelte Güterzug-Verbundlokomotive der Serbischen Staatseisenbahnen.* A. Buchterkirchen. (48) Dec. 4.
Die 2 Cl-Vierzylinderverbund-Heissdampflokomotiven der Württembergischen Staatseisenbahnen.* Dauner. (48) Dec. 18.

Railroads, Street.

Track and Line Improvements of the Coney Island & Brooklyn Railroad Company.* (17) Dec. 11.
Comparison of Operation of the New York and Paris Subway Systems.* Robert H. Whitten. (17) Dec. 11.
Details of Concrete Encasement for Elevated Railway Structure and of Special Forms Employed in Its Construction.* (86) Dec. 15.
The Concrete-Covered Steel Structure of the Forest Hills Extension of the Boston Elevated Ry.* (13) Dec. 16.
Recent Extensions of the Boston Elevated System.* (17) Dec. 18.
Train Operation in Chicago Freight Tunnels.* (27) Dec. 23.
Current Consumption.* R. S. Pilcher. (Paper read before the Mun. Tramways Assoc.) (96) Dec. 24.
London's First Elevated Electric Railway. W. B. Paley. (14) Dec. 25.
The Main Street Subway, Cambridge, Massachusetts.* (14) Jan. 1.
New Car House of the Capital Traction Company, Washington, D. C.* (17) Jan. 8.
Calculations of Tie Lines Between Street Railway Power Stations.* Ralph H. Rice. (17) Jan. 8.

Sanitation.

Refuse Disposal, and the New Refuse Incineration Plant for Milwaukee.* Samuel A. Greeley. (Paper read before the Engrs.' Soc. of Milwaukee.) (1) Nov.
Legal Aspects of the Smoke Nuisance. C. E. Brackenbury, Assoc. M. Inst. C. E. (Abstract of paper read before the Soc. of Brit. Gas Industries.) (66) Nov. 20.
Air Pollution by Smoke.* (66) Nov. 30.
Central Station Heating Plant at Crawfordsville, Indiana.* B. T. Gifford. (70) Dec.
The Quality of Effluents in Relation to Standards. Gilbert John Fowler. (Abstract of paper read before the Royal San. Inst.) (96) Serial beginning Dec. 10.
Standards of Purification of Sewage Disposal Effluents. (14) Dec. 11.
Itemized Cost of Storm Water Drain.* (14) Dec. 18.
Heating Plant for a Railway Storehouse.* J. Irving Brewer. (14) Dec. 18.
Sewage Disposal at Country Houses. John D. Watson. (Abstract of paper read before the Inst. of San. Engrs.) (14) Dec. 18.
Comparison of Forced-Circulation Hot Water, and Vacuum Steam Central Heating Plants.* Joseph T. Maguire. (13) Dec. 23.
Asphalt Joints for Sewer Pipe.* Carl Henneking. (14) Dec. 25.
Utilizing a Creek Valley Bed for a City Sewer.* Harlow Gale. (14) Dec. 25.
Specifications for Concrete Sewers at Richmond, Ind.* (86) Dec. 29.
Methods and Cost of Constructing Concrete Sewers at Richmond, Ind.* Fred. R. Charles. (86) Dec. 29.
The New Sewage Disposal Works, Sheffield, England. (From *The Surveyor.*) (14) Jan. 1.
Cost of Sewer Construction by Day Labor in Boston. (14) Jan. 1.
The New Refuse Destructor at Milwaukee. (14) Jan. 1.
A Discussion of Sewer Specifications. (14) Jan. 1.

*Illustrated.

Sanitation—(Continued).

Ocean Grove Sewage Disposal Plant.* Clyde Potts, M. Am. Soc. C. E. (14) Jan. 8.
The Design and Operation of Refuse Destructors. William F. Loveday. (Abstract of paper read before the Inc. Assoc. of Mun. and County Engrs.) (14) Jan. 8.
The Disposal of Dairy Wastes. A. Elliot Kimberly. (Abstract from *Quarterly Bulletin*, Ohio State Bd. of Health.) (14) Jan. 8.

Structural.

Contribution to the Study of Steel for Gears.* Louis P. M. Révillon. (71*a*) Vol. I.
Contribution to the Study of the Special Ternary Steels.* Albert M. Portevin. (71*a*) Vol. I.
The Strength of Nickel-Steel Riveted Joints, with Special Reference to Resistance to Slip. Ernst Preuss. (71*a*) Vol. I.
Cement and Sand for Concrete. (An informal discussion before the Boston Soc. of Civ. Engrs.) (1) Nov.
Metal Screed for Concrete Floor Slab.* Benjamin Fox. (Paper read before the Boston Soc. of Civ. Engrs.) (1) Nov.
The Design and Construction of the Large Gasholder Tank at Manchester.* Frank H. Robinson. (Paper read before the Manchester Assoc. of Students of the Inst. of C. E.) (66) Nov. 30.
Testing Metals for Hardness.* (41) Dec.
Deformed Bars vs. Round Rods Anchored, for Reinforced Concrete.* J. H. Toupet. (58) Dec.
The Gas Holder.* Lewis Vincent. (58) Dec.
The Setting of Portland Cement. H. K. G. Bamber. (Abstract of paper read before the Concrete Inst.) (67) Dec.
The Engineering Features of the Athletics' Baseball Park.* Michael Monaghan. (67) Dec.
The Limitations of Reinforced-Concrete Design. W. H. Thorpe, Assoc. M. Inst. C. E. (11) Dec. 3.
Old and New Gasholders at Gateshead.* (12) Dec. 3.
A Comparison of Timber and Concrete Piling on the Basis of Cost. E. W. Gaylord. (Abstract of paper read before the National Cement Users' Assoc.) (86) Dec. 8.
A Comparison of Reports on Tests of the Same Cement by Various Laboratories. Alexis Saurbrey. (13) Dec. 9.
A Comparison of the Cost of Two Methods of Concrete Construction: Separately-Molded Members vs. Monolithic Structures.* Mason D. Pratt, M. Am. Soc. C. E. (13) Dec. 9.
The Reconstruction of a Concrete Gas Tank Holder at Kingston, Ont.* (96) Dec. 10.
The Works of Drysdale & Co., Limited, Yoker, Glasgow.* (12) Dec. 10.
Reinforced Concrete Piles for a German Government Building.* (Abstract from *Zentralblatt des Bauvervaltung.*) (14) Dec. 11.
Recording Photographically the Setting of Cement.* H. Burchartz. (14) Dec. 11.
The Heine Boiler Works at St. Louis.* (14) Dec. 11; (15) Jan. 7.
The Construction of the Surety Building, Muskogee.* Donald D. Smith. (14) Dec. 11.
The Catastrophe at the Hamburg Gas Works.* (66) Dec. 14.
Design and Construction of a New Retort House at the Adderley Street Gas-Works of the Birmingham Corporation.* C. Carrington Barber. (Paper read before the Midland Junior Gas Eng. Assoc.) (66) Dec. 14.
Some Notes on Concrete Materials and Proportions. (86) Dec. 15.
Concrete Piles with Enlarged Bases.* Hunley Abbott. (13) Dec. 16.
A Concrete Pile with Concrete Shell and Removable Steel Core.* (13) Dec. 16.
Some Characteristics of Cement Brick. (96) Dec. 17.
Two New Codes of Professional Ethics. (14) Dec. 18.
The Reinforced Concrete Post Office Buildings, London. (14) Dec. 18.
The Foundations of the Paris, Illinois, Post Office.* (14) Dec. 18; (86) Dec. 29.
A Device for Testing Balk.* E. J. Dent. (100) Jan.
Industrial Applications of Reinforced Concrete.* M. M. Sloan. (9) Jan.
A Machine for Making Concrete Test Specimens.* H. Burchartz. (14) Jan. 1.
Concrete Boundary Monuments.* (14) Jan. 1.
Possible Use of Mineral Oils Mixed with Concrete. Albert Moyer, Assoc. Am. Soc. C. E. (14) Jan. 1.
Constructing Duplicate Buildings by Competing Gangs.* (14) Jan. 1.
Tests to Determine the Efficiency of Various Commercial Waterproofing Compounds for Concrete.* F. M. McCullough. (Abstract, Bul. 336, Univ. of Wis.) (86) Jan. 5.
Steel and Concrete, Their Co-ordination in Reinforced Concrete Construction.* J. F. Springer. (20) Jan. 6.
The Blake & Johnson Model Factory.* (20) Jan. 6.
A Composite Sand and Rock Foundation for a Tall Building.* (13) Jan. 6.

*Illustrated.

Structural—(Continued).

New Featherstone Foundry, Chicago.* (15) Jan. 7.
The Economy of Plain and Reinforced Concrete Columns.* Charles W. Hall. (14) Jan. 8.
German Airship Sheds.* (19) Jan. 8.
Le Ciment dans l'Eau de Mer.* (84) Nov.
Du Meilleur Procédé pour Déterminer le Commencement et la Durée de la Prise.* H. Laborbe. (Paper read before the Inter. Assoc. for Testing Materials.) (84) Serial beginning Nov.
Planches en Ciment. Armé.* (84) Nov.
Machine à Mouler les Tuyaux en Ciment.* (34) Dec.
Plancher Creux en Briques et Ciment Armé, Système Aragon.* Cr. Dantin. (33) Dec. 4.
Le "Royal Liver Building" de Liverpool.* J. Rabut. (33) Dec. 11.
Formsteinbalkendecke "System Seidel." Rich. Wuczkowski. (78) Nov. 23.
Neuere Englische Materialprüfmaschinen.* Max Kurrein. (48) Serial beginning Nov. 27.
Neuere Feuersichere Türkonstruktionen.* V. Wendt. (51) Serial beginning Dec. 1.
Der Eisenbeton-Unterbau des Grossen Gesbehälters am Gaswerk Grasbrook in Hamburg.* (51) Serial beginning Dec. 8.
Die Verwendung von Eisenflechtwerk zur Zugbewehrung von Betondecken.* Steinberger. (51) Dec. 22.
Bericht über das Verhalten Hydraulischer Bindemittel im Seewasser (nach den Versuchen auf Sylt.) (51) Dec. 22.

Topographical.

Emploi des Reseaux Géodésique pour les Etudes de Traces dans les Pays Neufs.* G. Maury. (30) Dec.

Water Supply.

The Venturi Meter and Its Use in Power Plants. C. G. Richardson. (Paper read before the National Dist. Health Assoc.) (70) Dec.
The Standley Lake Dam, near Denver, Colorado.* (67) Dec.
Flood Prevention and Land Fertilization by Basin Irrigation in the Sacramento San Joaquin Valley.* (13) Dec. 9.
The Shoshone Dam, U. S. Reclamation Service, near Cody, Wyo.* H. N. Savage, M. Am. Soc. C. E. (13) Dec. 9.
Water-Power Resources of Texas. James L. Starr. (27) Dec. 9.
Norwegian 250 000-h.p. Hydroelectric Development.* Einar A. Brofos. (27) Dec. 9.
Irrigation by an Oil-Driven Pumping Plant.* (14) Dec. 11.
The Water Supply of Springfield, Ohio.* Paul Hansen. (14) Dec. 11.
The Reclamation of the Arid Lands of the West.* (46) Dec. 11.
Moving Earth with Elevating Graders and Dump Wagons. (14) Dec. 11.
A Proposed Water-Supply Tunnel under New York City.* (13) Dec. 9; (14) Dec. 11.
A Brief Water Shortage at Springfield, Mass., Caused by Ice Crystals in the Gate Chamber of the Ludlow Reservoir. Elbert E. Lockridge, Assoc. M. Am. Soc. C. E. (13) Dec. 16.
Frazil. (96) Dec. 17.
The Hill View Reservoir, Catskill Water Supply.* (14) Dec. 18.
Design and Operation of a Mechanical Filter Plant.* (14) Dec. 18.
Public Water Supply for Purposes of Fire Extinguishing. C. W. S. Oldham. (Abstract of paper read before the Assoc. of Water Engrs.) (66) Dec. 21.
The Reclamation Project of the Idaho Irrigation Company.* (14) Dec. 25.
The Policy of Water Filtration. George C. Whipple. (Paper read before the N. Y. Assoc. of Private Water Companies.) (14) Dec. 25.
The Kensico Reservoir, Catskill Water Supply.* (14) Dec. 25.
Effect of Roughness of Bed on Depth of Water and Distribution of Velocity.* E. C. Murphy, M. Am. Soc. C. E. (13) Dec. 30.
A Large Blast at Morena Dam, California.* M. M. O'Shaughnessy, M. Am. Soc. C. E. (13) Dec. 30.
The Water Works of Marion, Ind.* Elkanah Hulley. (60) Jan.
U. S. Specifications for Reinforced Concrete Pressure Pipe.* (60) Jan.
Progress on the Rondout Pressure Tunnel.* John P. Hogan. (14) Jan. 1.
The Failure of a Small Concrete Dam.* Smith O. Steere. (14) Jan. 1.
Feed Water System of the New York Edison Company.* (14) Jan. 1.
Baths in German Schools.* (101) Jan. 1.
Cut and Cover Construction of the Catskill Aqueduct.* (14) Jan. 8.
Hydroelectric Development of the Minidoka Project.* (14) Jan. 8.
Théorie de l'Aspiration Pneumatique des Liquides.* L. Jannin. (37) Nov. 30.
Uber einige Grosse Europäische Wasserkraftanlagen und Ihre Wirtschaftliche Bedeutung.* Theodor Koehn. (Paper read before the Verband Deutscher Elektrotechniker zu Köln.) (97) Serial beginning Dec. 20.

*Illustrated.

Waterways.

Mechanical Transshipment of Railway and Water-Borne Freight, with Special Reference to the Port of New York.* H. McL. Harding. (65) Dec.
Fishguard Harbour.* (12) Serial beginning Dec. 3.
Records and Costs of Excavation on the Main Channel and Lock Work of the Panama Canal for the Year Ending June 30, 1909, with Some Summaries of Excavation Costs. (86) Dec. 8.
The Reinforced-Concrete Municipal Pier, Santa Monica, Cal.* Edwin Hall Warner, M. Am. Soc. C. E. (13) Dec. 9.
The Proposed Lakes-to-the-Gulf Deep Waterway.* (46) Dec. 11.
Some Methods and Costs of Work in Constructing the Gatun Dam for the Panama Canal.* (86) Dec. 15.
Pier 3 of the Boston Terminal of the Boston & Albany R. R.* (14) Dec. 25.
Modern Dredging Appliances for Waterways.* J. A. Seager. (10) Jan.
Sabine Bank Light Station, Tex.* T. P. Brown. (100) Jan.
Decline of Water Transportation on Western Rivers.* C. McD. Townsend. (100) Jan.
Sinking Stone Dumps with Water Jet.* Henry N. Babcock. (100) Jan.
The Ohio River. F. W. Altstaetter. (100) Jan.
A Machine for Cutting Off Piles.* Clarence Coleman. (100) Jan.
Notes on the Construction of a Concrete Dam at McGrew Shoals, Ala.* Henry Jervey. (100) Jan.
The Army Engineer and River Improvement. J. M. Dickinson. (100) Jan.
An Emergency in the Life of a River.* Robert S. Taylor. (100) Jan.
Two Hydroelectric Developments on the Peshtigo River.* (14) Jan. 1.
The Paxton Creek Flood Controlling Works.* R. M. Riegel. (Abstract from *Cornell Civil Engineer.*) (14) Jan. 1.
The Proposed Lake Washington Canal, Seattle, Wash.: A Great Engineering Project.* Archibald O. Powell, M. Am. Soc. C. E. (13) Jan. 6.
Excavating Submerged Rock with a Drill Boat.* (14) Jan. 8.
Submarine Sound Signals. (19) Jan. 8.
Notes sur les Axes Hydrauliques de l'Influence du Débit sur la Forme des Axes en un Lit Donné.* J. Duvigneaud. (30) Dec.
Die Bauanlagen zur Herstellung des Betonmauerwerkes für die Schiffschleusen des Panama Kanales in Pedro Miguel und Miraflores.* Walter Rowland. (48) Dec. 4.
Uber Flussregime und Talsperrenbau in den Ostalpen.* Max Singer. (53) Serial beginning Dec. 10.
Der Neue Müke-Hafen und Seine Kohlenladeeinrichtung.* H. Nölke. (48) Dec. 11.

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*Illustrated.

Vol. XXXVI. JANUARY, 1910. No. 1.

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INSTITUTED 1852

PAPERS AND DISCUSSIONS

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CONTENTS

PLATES

Vol. XXXVI. JANUARY, 1910. No. 1.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

THE IMPROVED WATER AND SEWAGE WORKS OF COLUMBUS, OHIO.

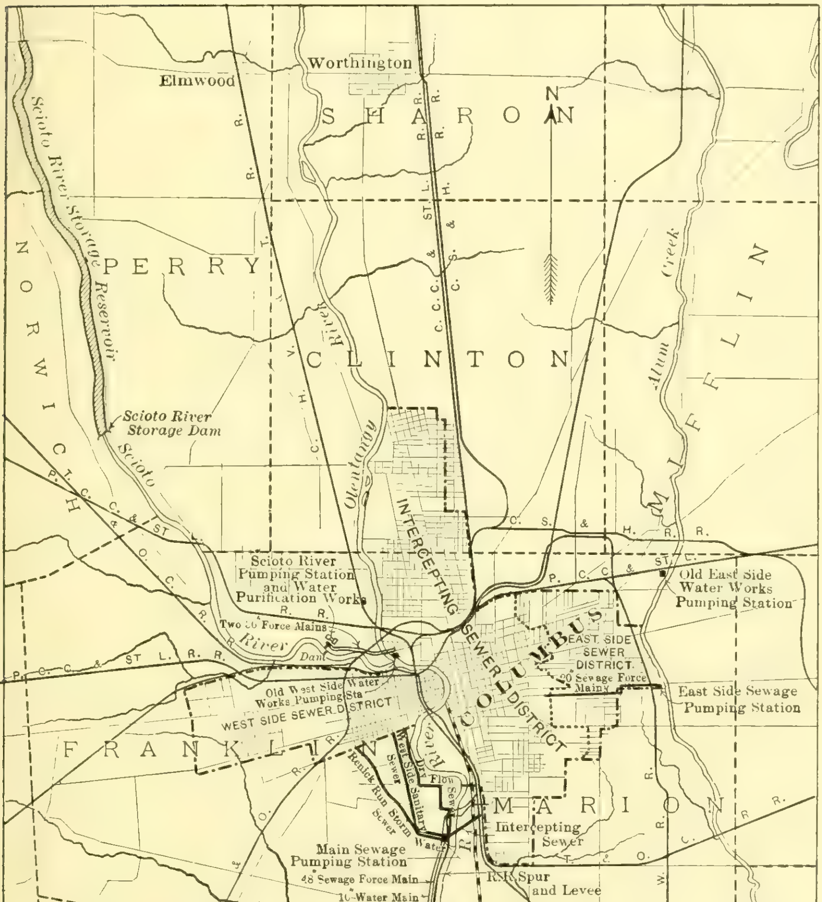
By John H. Gregory, M. Am. Soc. C. E.

To be Presented March 2d, 1910.

In 1904 the City of Columbus, Ohio, began the construction of two important sanitary improvements which have recently been completed, and it is the purpose of this paper to describe them. They include works for improving the water supply and for purifying the dry-weather flow of sewage.

Previous to 1904, or, more correctly speaking, previous to the completion of the new works, it may be said that conditions in Columbus, as in some other American cities, were far from satisfactory. The water supply, which had been mainly from ground-water sources, but was augmented at times by drawing directly from the river intakes, normally very hard, had gradually grown worse, typhoid fever had been a constant menace, a very severe epidemic having occurred in January and February, 1904, and on more than one occasion a water famine had been imminent. In periods of extreme dry weather, practically the whole flow of the Scioto River above Columbus was taken for water supply purposes and returned to the river as sewage a short distance west of the southerly part of the city, causing thereby a nearly stagnant pool of slightly diluted sewage, the odors arising from

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.



MAP OF
COLUMBUS AND VICINITY
SCALE OF MILES
Worthington
Elmwood
SHARON
PERRY
CLINTON
NORWICH
MIFFLIN
FRANKLIN
MARION
COLUMBUS
Scioto River Storage Reservoir
Scioto River Storage Dam
Scioto River Pumping Station and Water Purification Works
Old East Side Water Works Pumping Station
East Side Sewage Pumping Station
EAST SIDE SEWER DISTRICT
WEST SIDE SEWER DISTRICT
INTERCEPTING SEWER DISTRICT
Main Sewage Pumping Station
Sewage Purification Works
Intercepting Sewer
R.R. Spur and Levee
Olentangy River
Alum Creek

FIG. 1.

which, carried up into the city by the prevailing winds, gave cause for great complaint. A somewhat similar condition of affairs existed on the east side of the city, where the sewage was discharged into Alum Creek. Before proceeding to the detailed descriptions of the works built to relieve these conditions, certain general information relating to the city will be given.

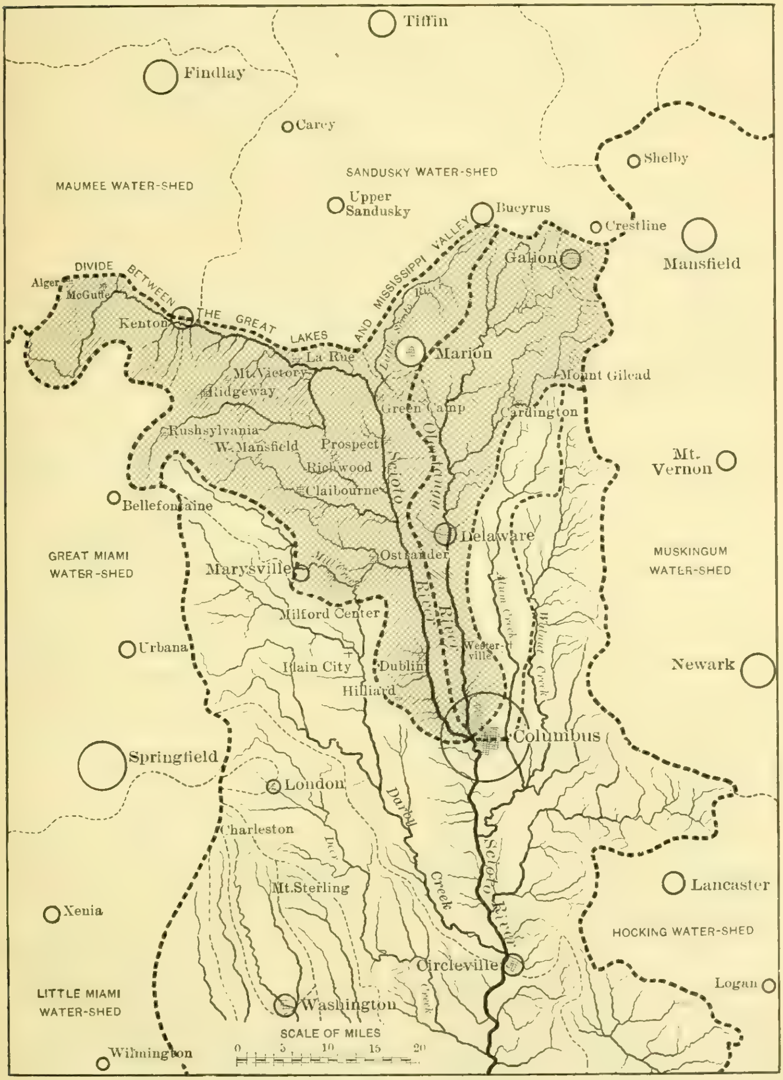
Location.—Columbus, the capital of the State of Ohio, is an inland city located about 30 miles southwest of the geographical center of the State, and about 100 miles from Lake Erie. The general elevation of the city is about 780 ft. above sea level. Fig. 1 is a map of the city and vicinity.

Population and Area.—The population of Columbus, as given by the United States Census, was 88 150 in 1890, and 125 560 in 1900. The growth of the city has been very rapid in recent years, and, from the best information obtainable, it is believed that the population in 1907 was about 170 000, and that, by 1910, it will have increased to about 200 000. The area within the corporate limits of the city in 1908 was 16.81 sq. miles.

Precipitation.—The mean annual precipitation at Columbus, from the records of the Weather Bureau of the United States Department of Agriculture, for the 29 years, 1879 to 1907, is 36.75 in. The wettest year was 1882, with a total precipitation of 51.30 in., and the driest, 1901, with a total of 26.53 in. The greatest monthly precipitation was 9.59 in., in May, 1882, and the least, 0.18 in., in November, 1904.

Temperature.—Tables 1 and 2 contain data relative to the temperature conditions in Columbus, also compiled from the records of the Weather Bureau. Table 2 is of especial interest as indicating the severity and duration of the periods of cold weather to which the sewage purification works may be exposed. The severest period in the past was probably in the winter of 1898-99, when, although the total number of consecutive days that the temperature was below 32° Fahr. was only 13, on 10 days the temperature was 20° or below, on 7 days 10° or below, on 4 days 0° or below, and on 2 days —10° or below.

Water-shed of Scioto River.—Columbus lies at the junction of the Olentangy and Scioto Rivers. Above the junction the water-shed of the Scioto has an area of about 1 050 sq. miles, and that of the Olentangy about 514 sq. miles; below the city, at the site of the sewage



WATER-SHED OF SCIOTO RIVER NEAR COLUMBUS

FIG. 2.

purification works, the water-shed of the Scioto, shown in Fig. 2, has an area of about 1 580 sq. miles. Above Columbus this water-shed is in general flat and largely devoted to agriculture, being highly cultivated. As but few areas are wooded, the river is more or less flashy.

TABLE 1.—TEMPERATURE CONDITIONS AT COLUMBUS, OHIO.

		Degrees Fahr.
Mean annual	1879 - 1907	52.1
Warmest summer	June, July, Aug., 1901	76.0
Coolest summer	June, July, Aug., 1882	70.1
Mildest winter	Dec., Jan., Feb., 1889 - 1890	41.4
Coldest winter	Dec., Jan., Feb., 1903 - 1904	23.4
Warmest month	July, 1901	79.9
Coldest month	Jan., 1893	18.8
Highest recorded observation, once in	1901	104.0
Lowest recorded observation, once each, in	1879, 1884, 1899	—20.0

TABLE 2.—PERIODS OF SEVERE WINTER WEATHER AT COLUMBUS, OHIO. Temperature Given in Degrees, Fahrenheit.

Winter of:	CONSECUTIVE NUMBER OF DAYS THAT MEAN DAILY TEMPERATURE WAS:				
	32° or below.	20° or below.	10° or below.	0° or below.	—10° or below.
1878–1879	38	8–6–2–2	4–4–1	3	....
1894–1895	30	2–7–10	1–6–1	1	....
1904–1905	29	3–3–7–2–4–1	2–2–3	2	....
1901–1902	27	2–4–4–4–3	3	....	....
1880–1881	27	6–1–3	5–1	2	....
1892–1893	24	6–12	8–2	1	....
1891–1892	23	1–1–2–2–3	1	....	....
1886–1887	20	3–4–3–2	2–2–2	....	....
1884–1885	18	5–8	2–7	1–1	....
1884–1885	18	7–5–1	2–2–2	....	....
1896–1897	14	8	5	2	....
1898–1899	13	10	7	4	2
1883–1884	13	2–2–3	1–2	1	....
1885–1886	11	9	5	3	....
1883–1884	11	7	5	2	....

Throughout the water-shed the rock is limestone, and is covered by drift of varying thickness, although at many places it is exposed. The water is hard, carrying considerable amounts of the carbonates and sulphates of lime and magnesia, and it is highly turbid during freshets. The river, to a certain degree, is polluted, although not as much so as other rivers flowing through more thickly populated dis-

tricts, but the drainage which it receives from small cities, villages, and public institutions is sufficient to render it unfit for use as a public water supply without purification.

TABLE 3.—POPULATION ON THE WATER-SHED OF THE SCIOTO RIVER. Drainage Area at Columbus, 1 050 sq. miles.

	POPULATION:		
	1890.	1900.	1908.
Total population, towns having more than 4 000 inhabitants	13 330	18 030	21 790
Places having from 1 000 to 4 000 inhabitants	4 220	4 690	8 450
Rural population (being all the remainder)	45 260	46 280	42 900
Total population on water-shed	62 810	69 000	73 140
Population per square mile, towns having more than 4 000 inhabitants	12.7	17.2	20.8
Places having from 1 000 to 4 000 inhabitants	4.0	4.5	8.0
Rural population per square mile	43.1	44.0	40.9
Total population per square mile	59.8	65.7	69.7

Table 3 gives the population on the water-shed of the Scioto above Columbus for the years 1890 and 1900, and the estimated population in 1908, made up from figures compiled by Paul Hansen, Assoc. M. Am. Soc. C. E., Assistant Engineer, Ohio State Board of Health, from which it will be noticed that the population is largely rural.

TABLE 4.—DEATH RATES IN COLUMBUS, OHIO.

Year.	Population.	Total deaths from all causes.	Total deaths per 100 000 population.	Deaths from typhoid fever.	Deaths from typhoid fever per 100 000 population.
1898	116 000	1 390	1 200	33	28
1899	120 000	1 622	1 350	31	26
1900	125 600	1 776	1 410	53	42
1901	131 000	1 551	1 190	47	36
1902	136 500	1 578	1 150	44	32
1903	142 000	1 787	1 260	46	32
1904	148 000	2 080	1 410	195	132
1905	155 000	1 899	1 220	109	70
1906	162 500	2 033	1 250	52	32
1907	170 000	2 117	1 250	48	28
1908	178 000	2 156	1 210	170	96
1909	186 500	1 039*	....	5*	...

* For first six months only.

Death Rates.—Table 4, also compiled by Mr. Hansen, gives the total death rates and the death rates from typhoid fever in Columbus for the ten years prior to 1908 and the rates for 1908, during the latter part of which year the water purification works were placed in operation; also the total deaths and deaths from typhoid fever for the first six months of 1909. The typhoid death rates in several of the years indicate only too clearly that purification of the water supply was needed, and that the rates in the other years were not higher is probably due to the fact that a large percentage of the water was obtained from underground sources.

I.—THE IMPROVED WATER-WORKS.

Historical.—The water supply of Columbus was formerly obtained mainly from ground-water sources. The first works were situated on the east bank of the Olentangy River, just above its junction with the Scioto. The supply was obtained from a well, 20 ft. in diameter, and from a brick filtering gallery, 256 ft. in length, adjacent to which was built what is known as the West Side Pumping Station, the works being first put in operation on May 1st, 1871. The city then, as at present, was supplied by direct pumping service. No distribution reservoirs or stand-pipes were provided; reservoirs, however, were entirely out of the question on account of the topography of the city and the surrounding country.

From time to time the ground-water source of supply was increased by extending the filtering galleries and conduit systems under and along the Olentangy and Scioto Rivers, until a total length of 13 097 ft. of brick and iron conduit, 42 in. in diameter, had been provided.

The most recent extension to the conduit system was made in 1897 and 1898, when an additional 3 000 ft. of 42-in. cast-iron pipe were laid. At the time this new conduit was built, 37 tubular wells, 6 in. in diameter, were sunk along its line at depths varying from 20 to 58 ft. below its bottom, most of them, when they were drilled, being flowing wells at the conduit elevation. The laying of this additional conduit was undertaken as a precautionary measure, to provide a duplicate system for use in case of failure of the old brick conduit, warning that a collapse was likely to occur having been given by the caving in of the old conduit at several points near its upper end. The extension of the underground source of supply did not keep pace with the increasing consumption, and, each year since the works were first

PLATE I.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

FIG. 1. VIEW OF DAM DURING CONSTRUCTION.

FIG. 2.—VIEW OF FINISHED DAM, FROM EAST BANK.

FIG. 3.—VIEW OF DAM, FROM EAST EMBANKMENT.
(5 ft. of Water on the Crest.)

FIG. 4.—VIEW OF SCIOTO RIVER PUMPING STATION AND
WATER PURIFICATION WORKS.

established, more or less water was obtained directly from the Olentangy and Scioto Rivers, in the last few years, however, only from the Scioto.

In 1889, it having been considered that the underground sources of supply tributary to the West Side Pumping Station had been developed to as great an extent as was profitable, attention was turned to Alum Creek, the stream flowing along the eastern boundary of the city. A second pumping station, known as the East Side Pumping Station, was built on the west bank of the creek, and pumping was begun on May 5th, 1891, from a brick well, 25 ft. in diameter, and from 32 tubular wells, 6 in. in diameter and from 60 to 65 ft. in depth. As was the case at the West Side Pumping Station, the supply from the underground sources at times was insufficient and was augmented by drawing indirectly from Alum Creek.

The construction of a storage reservoir on the Scioto River first received consideration in 1879. In 1886 plans for a low dam across the river were prepared by Mr. John B. Gregory, but the cost of the proposed undertaking was so large that the project was laid aside in favor of additional filtering galleries. In 1893 the project was again revived, when a storage reservoir was reported as necessary by Rudolph Hering, M. Am. Soc. C. E., he favoring the Scioto River as being a better source of supply than other available streams.

It was not until 1897, however, that definite steps were taken to secure an additional supply. Extended surveys and studies were then made by Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the Department of Public Improvements, and early in 1898 Mr. Griggs recommended the construction of a curved concrete overflow dam, 30 ft. high, across the Scioto River, about 5.5 miles northwest of the West Side Pumping Station. In the spring of the same year, general plans of the proposed work were submitted to the Ohio State Board of Health, and in their approval a recommendation was made that the height of the dam be increased from 30 ft. to 50 ft., as a much greater storage could thereby be provided.

In June, 1898, the whole subject was reviewed by James D. Schuyler, M. Am. Soc. C. E., Consulting Engineer, and in July of the same year, he endorsed the proposed construction and concurred in the recommendation that the 50-ft. dam be built. In the course of the next two years several attempts were made to begin the construction, but, owing to legal and other difficulties, they were unsuccessful.

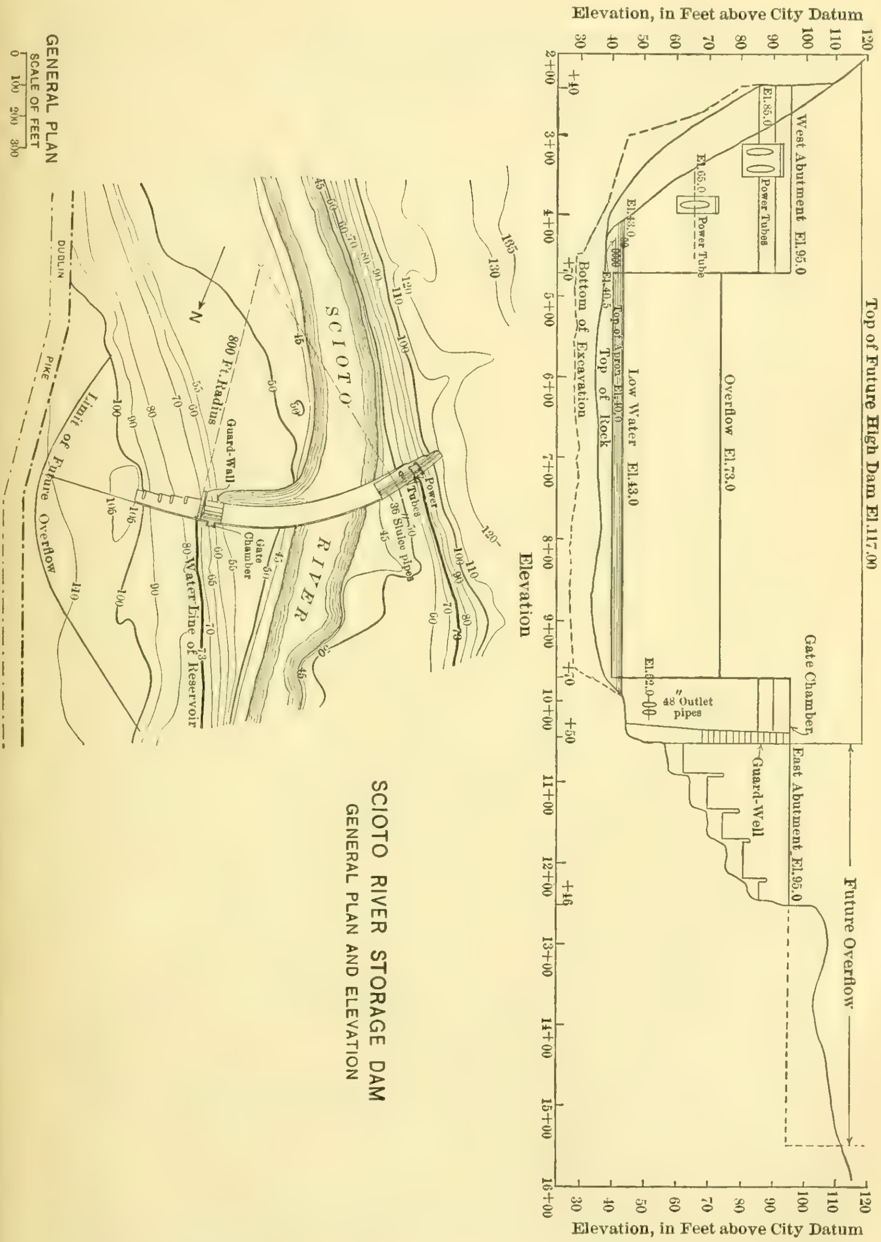
In 1900 the question of an additional supply was again taken up, and Samuel M. Gray, M. Am. Soc. C. E., Consulting Engineer, was asked to report, not only on the additional supply, but also on the improvement and extension of the whole water-works system. In the report submitted by Mr. Gray, in February, 1901, he endorsed the previous recommendation that the Scioto River be adopted as a source of supply and that a masonry dam 52 ft. high and an impounding reservoir be built. He advised also that water purification works, consisting of a softening and mechanical filtration plant, be built adjacent to the West Side Pumping Station, that a gravity conduit be laid from the storage reservoir to the purification works, that the East and West Side Pumping Stations be abandoned, that a new pumping station with entirely new equipment be built, and that the distribution system be revised and reinforced.

Following the presentation of Mr. Gray's report, steps were taken to inaugurate the construction of the work outlined and recommended by him, but it was not until 1904 that the necessary funds were appropriated and the work of construction commenced.

Brief Outline of the New Works.—In the development of the new works, the scheme outlined in Mr. Gray's report has in general been followed, but modifications have been made where further study indicated that it would be desirable. Briefly stated, a masonry dam, raising the water level 30 ft., and a storage reservoir, have been built on the Scioto River, about 5.5 miles northwest of the old West Side Pumping Station. About 4.5 miles below the dam a new pumping station and purification works have been built. No appropriation for the gravity conduit was made, and therefore the river is used as a conduit, the water flowing down the river from the dam to the new pumping station. The water is here raised by low-lift pumps to the purification works, is softened and filtered, and then pumped from the new station through two 36-in. force mains connecting with the distribution system in the city. The old East Side and West Side Pumping Stations are no longer in service, the work which they formerly did being now performed by the new pumping station. The location of the new works relative to the city is shown on Fig. 1.

THE SCIOTO RIVER STORAGE DAM AND RESERVOIR.

Type of Structure.—The Scioto River Storage Dam, as it is officially known, is a concrete structure about 1 006 ft. long, consisting of



SCIOTO RIVER STORAGE DAM
GENERAL PLAN AND ELEVATION

Fig. 3.

two abutment sections, one on each bank of the river, with an overflow or rollway section between. The dam is of the curved or arched type, with the convex side up stream, the vertical up-stream face for a length of 810 ft. being built in plan to a radius of 800 ft.

In Mr. Gray's report it was recommended that a 52-ft. dam, or so-called high dam, be built, that is, a dam which would raise the water level 52 ft., but, owing to reasons purely local, and having no relation to the design of the structure, the 30-ft. or low dam was built. The foundations and abutment sections, however, have been constructed so that at a future date the dam can be raised 22 ft. to the full height recommended. Fig. 3 is a general plan and elevation of the dam.

The crest of the present overflow is at Elevation 73.0, or 30 ft. above former mean low water, the abutment sections on either side rising to Elevation 95.0, or 22 ft. above the crest of the overflow. With the high dam, the crest of the future overflow will be at Elevation 95.0 and the top of the abutment section at Elevation 117.0.

Profile of Dam.—The profile of the dam as adopted is substantially that of the 52-ft. dam recommended by Mr. Gray, a few slight changes in the dimensions, however, having been made in order to secure a somewhat smoother outline. Although the dam is of the curved type, it has a gravity section, and in the design no consideration was given to the effect of any possible arch action.

The factors controlling the design of the profile are discussed so fully in Mr. Gray's report that they will not be considered here at length, it being sufficient to state that, in addition to the water pressure on the back of the dam, allowance was made for an upward water pressure equal to two-thirds of the head at the back of the dam and decreasing uniformly to the toe, and for an ice thrust of 34 000 lb. per lin. ft. of dam applied at the crest of the future overflow, or 22 ft. below the top of the high dam. In all the computations relating to the stability of the dam, the weight of the concrete was assumed as 140 lb. per cu. ft.

Two profiles of the 52-ft. dam are shown, Fig. 4, giving the lines of pressure when the reservoir is full and empty, and Fig. 5, giving the lines when the reservoir is filled to 22 ft. below the top, that is, to the crest of the future overflow.

By reference to Fig. 4 it will be seen that with the reservoir empty, or with the reservoir full and water pressure only on the back of the

dam, the lines of pressure fall inside the middle-third limit. With the reservoir full and with upward water pressure on the base of the dam, the line of pressure falls outside the middle-third limit. As the condi-

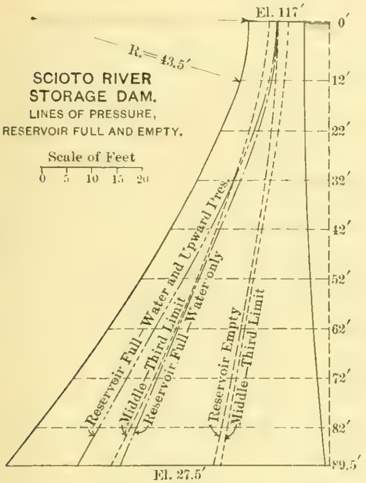


FIG. 4

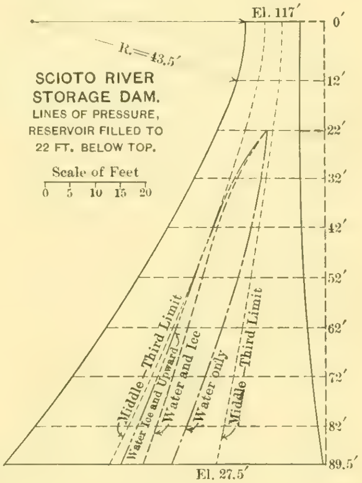


FIG. 5

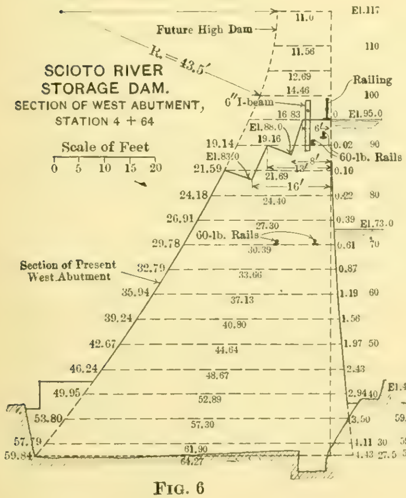


FIG. 6

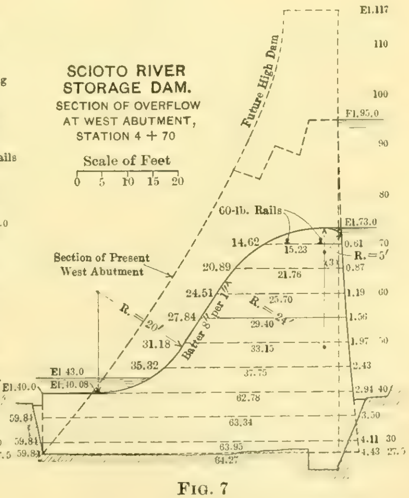


FIG. 7

tion of a full reservoir and of an upward water pressure of the amount assumed would occur so infrequently, and especially as the duration of the period when the reservoir would be full would be only a few

hours, and, further, as it would probably require several days for the upward pressure to equal the amount assumed, the increase in section necessary to bring the line of pressure inside the middle-third limit was not considered warranted.

With the reservoir filled to the crest of the future overflow, it will be seen, by referring to Fig. 5, that the lines of pressure due to water pressure only, to water pressure and ice thrust, and to water pressure, ice thrust, and upward pressure, all fall inside the middle-third limit.

West Abutment.—The section of the present west abutment is shown by the full lines in Fig. 6; the dotted lines indicate what the full section of the west abutment will be when the dam is raised 22 ft. At the top of the present section steps have been left for the purpose of providing a bond with future work. In addition to the steps, 6-in. I-beams, 10 ft. long and 5 ft. apart, have been built into the masonry to provide an additional bond between the old and new work.

Inasmuch as it is probably only a question of time until the dam will be raised, no attempt at architectural ornamentation was made, that being left to be considered with future construction.

Present Overflow.—The present overflow has a rollway section with an apron extending out a few feet at the toe, as shown in Fig. 7. Superimposed on this section are shown the sections of the present and future west abutments. The overflow is 500 ft. long, and was designed to discharge a maximum rainfall of 6 in., on the drainage area of 1 032 sq. miles above the dam, flowing off in 24 hours, or about 166 500 cu. ft. per sec. To discharge this quantity would require a depth of about 21.7 ft. on the overflow. In the flood of March, 1898, the greatest of which any records are available, the maximum discharge of the river was estimated at about 50 000 cu. ft. per sec. A depth of only about 10 ft. on the overflow would be required to pass this quantity of water. Owing to its length, the possible depth of water flowing over it, and the possibility of raising the dam, it was not considered advisable to attempt to bridge the overflow. When the dam is raised, the present overflow will become a part of the west abutment, and especial care will have to be taken to insure a satisfactory bond between the old work and the new. In all probability some method of steel reinforcement will be required.

36-in. Sluice-Pipes.—In order to care for the ordinary flow of the river during construction, six lines of 36-in. cast-iron pipe were built

through the west abutment of the dam, the up-stream end of each being provided with a 36-in. circular sluice-gate. In case it should ever be desired to drain the reservoir to the lowest possible point, these gates could be used for this purpose, but, under ordinary conditions, they will remain closed.

Power Tubes.—It was pointed out in Mr. Gray's report that, with the 52-ft. dam, a considerable amount of water-power could be developed at the dam from the water overflowing in excess of that required by the city. In order to provide for the possible future development of this power, should the present dam be raised, three so-called power tubes have been built into the west abutment, two at Elevation 85.0 and one at Elevation 65.0, for connecting with future penstocks. Each tube is a riveted steel pipe, 9 ft. in diameter and $\frac{5}{16}$ in. thick, reinforced with bent steel angles placed circumferentially. Reinforced concrete bulkheads have been built in the ends of each tube, and on the up-stream ends heavy flanges have been provided to which gate-frames, screens, or other construction can be bolted.

Gate-Chamber.—The gate-chamber is just east of the present overflow and on the up-stream side of the present east abutment. No superstructure has been provided in the present construction, as it would be necessary to remove it, should the dam be raised. Instead, an operating-room has been built in the upper part of the gate-chamber, with its roof flush with the top of the present east abutment. Should the dam be raised, the roof only would be removed, thereby permitting the gate-chamber to be extended up to the top of the high dam. A gate-house, or an operating-room similar to the present design, could then be built, as desired. The floor of the operating-room is at Elevation 84.0, or 11 ft. above the crest of the overflow, and would not be flooded except for a short time during a period of very high water, in fact, higher than that of the flood of March, 1898. A manhole in the roof and a ladder extending to the floor below furnish access to the operating-room.

Below the operating-room, the wells are in duplicate, water being admitted through openings in the up-stream face of the gate-chamber. In each up-stream well two 36 by 60-in. Coffin sluice-gates have been provided, permitting water to be drawn at different levels. An additional sluice-gate of the same size, at a higher elevation, will be added should the dam be raised. Three sets of grooves for stop-planks and

screens have also been provided. In each down-stream well is placed a 48-in. circular sluice-gate, each connecting directly with a line of 48-in. cast-iron pipe extending through the dam. These two lines of 48-in. pipe will connect with the future conduit from the dam to the water purification works.

As mentioned before, this conduit has not been built. Under ordinary conditions, the reservoir is full and the entire flow of the river passes over the overflow and thence down to the purification works, where a portion of it is pumped to the settling basins. When the amount taken by the purification works is in excess of the flow of the river, however, the deficit is made up by drawing from the storage in the reservoir, the water being drawn through the gate-chamber and discharged again into the river just below the dam. Under such conditions, fine screening at the gate-chamber would be useless, and hence coarse screens only have been provided, sufficient to keep out floating brush and logs from the wells.

These coarse screens at present extend from the bottom of the gate-chamber up to about the level of the crest of the overflow; above them are placed stop-plank gates reaching to the floor of the operating-room. The twelve screens consist of 3½ by ⅜-in. flat steel bars, 4 in. from center to center, held in steel frames 3 ft. 11 in. high and about 4 ft. 9 in. wide. The four stop-plank gates are 3 in. thick, and are made up and bolted together in sets, 4 ft. 2 in. high and 4 ft. 9 in. wide. The stop-plank gates and screens are raised or lowered by a traveling screen lifter, moving up or down in the grooves, and hung from a triplex block.

Future Overflow.—The future overflow is located at the east end of the dam, and at present that portion which has been built forms the east abutment of the dam. It has a rollway section, the down-stream face having the same outline as the present overflow, as shown in Fig. 8. The present construction has a length of 196 ft. In

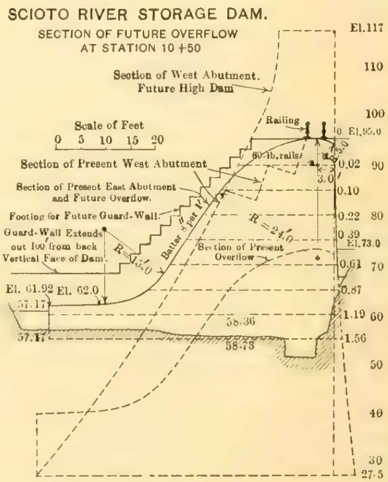
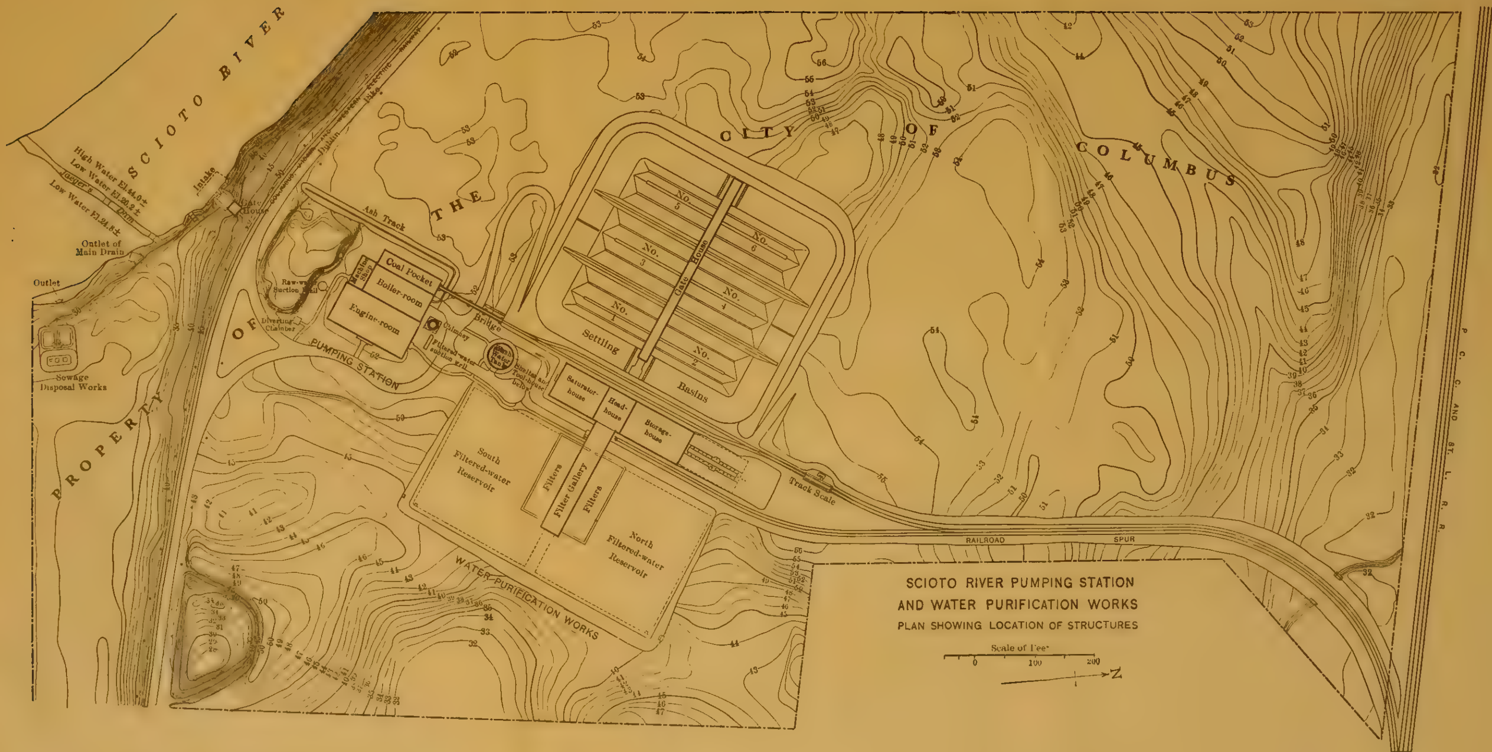


FIG. 8.

PLATE II.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



SCIOTO RIVER PUMPING STATION
AND WATER PURIFICATION WORKS
PLAN SHOWING LOCATION OF STRUCTURES

Scale of Feet
0 100 200

order to provide an overflow 500 ft. in length, the remaining 304 ft. will be excavated in rock. On the down-stream side, four guide-walls have been built in order to prevent lateral movement of the water immediately at the foot of the rollway. A guard-wall, backed up with earth, will also be built, extending out about 100 ft. from the back vertical face of the dam. The foundation and footing for this future guard-wall have been built with the present construction.

Foundation.—The foundation on which the dam is built is Columbus limestone, the depth of the excavation being governed largely by the character of the rock. Under the overflow section, the rock was excavated to a depth sufficient to protect the foundation from the action of water moving at a high velocity, the rock here being hard, and free from clay pockets; seams, however, are found at various angles. Under the west abutment, between Elevations 53.0 and 62.0, the rock was softer than that either above or below, and some large vertical cracks, filled with clay and extending back into the hillside, were found. The excavation, therefore, was carried to greater depths than was contemplated originally. The stratum of softer rock was also found on the east bank.

A cut-off trench, varying in depth from 3 to 5 ft. and about 5.5 ft. wide, was excavated under the up-stream portion of the dam. A part of the trench was excavated by a drill mounted on a horizontal bar, light charges of powder being used to loosen the rock, but satisfactory results were not obtained until an Ingersoll-Sergeant channeling machine was installed.

Concrete.—The dam was built mainly of concrete, but large stones were bedded in it to a certain extent, the percentage of such stones in the whole, however, being small. Lehigh Portland cement was used throughout the work, and was furnished to the contractor by the City. The ballast for the concrete was crushed limestone screened into three sizes: No. 1, 0.25 to 0.75 in.; No. 2, 0.75 to 1.5 in.; and No. 3, 1.5 to 3 in.

During the fall of 1904, when about 6 300 cu. yd. of concrete were placed, the materials were mixed in the proportion of 1 volume of cement, 3 volumes of sand, and 2 volumes each of Nos. 1, 2, and 3 ballast. During 1905, when the remainder of the concrete was placed, the proportions were changed to 1 of cement, 2.71 of sand and 2.29 of each of the three grades of ballast. The two mixtures above mentioned were used in the main body of the dam. On the face of the present

and future overflows, and on the vertical sides of the abutment sections next to the present overflow, for a depth of 1 ft., and on the top of the abutment sections, for a depth of 6 in., a richer mixture was used, the concrete containing 50% more cement than that in the main body of the dam.

The total volume of concrete placed in the dam was 56 330 cu. yd., in which 56 870 bbl. of cement were used, giving a ratio of 1.01 bbl. of cement per cubic yard of concrete, and agreeing almost exactly with the specifications, which stated that "in general, not less than one barrel of cement will be used in each cubic yard of concrete."

Reservoir.—The reservoir formed by the construction of the dam is peculiar in shape, as it is very long and narrow, the total length being about 5.8 miles and the mean surface width about 516 ft.; the maximum width is about 820 ft., and the minimum about 200 ft. The area of the water surface is about 363 acres, and the mean depth about 14.5 ft.; the maximum depth, about 35 ft., is just above the dam. The total volume of water impounded by the present or 30-ft. dam, up to Elevation 73.0, is 1 720 000 000 gal., of which 1 487 000 000 gal. are available, taking low water at Elevation 55.0. The total volume which would be impounded by the 52-ft. dam would be 5 681 000 000 gal., of which 5 448 000 000 gal. would be available.

Inasmuch as the water was to be purified by filtration, it was not considered necessary to strip the surface of the reservoir. All trees were cut down, and all stumps and roots 1 in. or more in diameter were grubbed out to a depth of at least 1 ft. below the surface, after which the material was burned. The surface of the ground was then burned over. There were a few buildings on the site of the reservoir, one of which would have been submerged. Some of these buildings were moved to higher ground; the others were burned or torn down. One old bridge was removed, and a new one, 540 ft. in length, was built to replace it. The new bridge was designed and erected under the direction of Mr. Walter Braun, County Surveyor, the City paying 70% of the cost. In addition to the above, about 3.9 miles of roads were relocated and constructed.

Cost.—Table 5 gives the cost of the reservoir and dam, and Table 6 gives the cost per million gallons of capacity. In order that the figures may be understood clearly, one or two items need explanation. In the reconstruction of the bridge and the approaches, as previously stated,

the City bore 70% of the cost, but the figures in Tables 5 and 6 give the total costs, and not the proportionate part paid by the City. Similarly, the figures given for the cost of engineering include the cost of engineering chargeable to the bridge, although this work was not done under the direction of the City.

TABLE 5.—COST OF SCIOTO RIVER STORAGE RESERVOIR AND DAM.

Reservoir.					
Land	452	acres	@ $334		$150 850
Clearing and grubbing	256	acres	@ 79		20 200
Moving buildings					2 440
Reconstruction of roads	3.9	miles	@ 12 670		49 400
Reconstruction of bridge					65 800
Convenience stations	2		@ 880		1 760
Keeper's house, repairs, and grading					1 760
Total cost of reservoir					$292 210
Dam.					
Excavation.					
Dry earth	10 850	cu. yd.	@ $0.40	$4 340	
Wet earth	5 330	cu. yd.	@ 0.80	4 270	
Rock	29 900	cu. yd.	@ 1.50	44 870	$53 480
Masonry and steel.					
Concrete	55 710	cu. yd.	@ $4.94	$275 340	
Steel rails and splices	28.7	tons	@ 35.00	1 000	
Structural steel	11 460	lb.	@ 0.045	520	276 860
Gate chamber.					
Concrete	620	cu. yd.	@ $4.94	$3 060	
Steel and cast iron	18 430	lb.	@ 0.045	820	
48-in. sluice-gates	2		@ 600.00	1 200	
36 by 60-in. sluice-gates	4		@ 600.00	2 400	
48-in. cast-iron pipe	28.5	tons	@ 26.84	770	
Screens, stop-planks and lifters				580	8 830
36-in. sluice-pipes.					
Steel and cast iron	5 270	lb.	@ $0.042	$220	
36-in. sluice gates	6		@ 263.00	1 580	
36-in. cast iron pipe	65.3	tons	@ 24.96	1 630	3 430
Power tubes	3				3 640
Railing	1 000	lin. ft.	@ 1.75		1 750
Total cost of dam					$347 990
SUMMARY.					
Reservoir					$292 210
Dam					347 990
					$640 200
Total cost of construction, exclusive of land					$489 350
Engineering.					
Pay-roll				$27 540	
Supplies				3 560	
Expenses				2 230	$33 330
Percentage for engineering					6.81

The item for engineering needs further explanation. Prior to 1904, when the engineering force was organized for carrying on the work

of construction, and extending over a series of years during which the preliminary studies of the dam, the surveys of the reservoir, and exploration of the dam site were made, no separate account was kept of the cost of engineering, it being included in the general engineering expenses of the City. After the writer became connected with the work, he made an attempt to ascertain this preliminary cost, but was unable to do so. The cost of engineering given in Tables 5 and 6, therefore, does not include this preliminary work, but does include the preparation of all the contract drawings and specifications, and the engineering expenses during the full period of construction.

TABLE 6.—COST, PER MILLION GALLONS, OF SCIOTO RIVER STORAGE RESERVOIR AND DAM.

Items.	Total cost.	Cost, per Million Gallons.	
		Total capacity, 1 720 000 000 gal.	Available capacity, 1 487 000 000 gal.
Land	$150 850	$88	$101
Reservoir, exclusive of land	141 360	82	95
Dam	347 990	202	234
Total, exclusive of engineering	$640 200	$372	$430
Engineering	33 330	19	22
Total	$673 530	$391	$452

Contractors, and Progress of Work.—The preparation of the drawings and specifications was begun in January, 1904. The main construction work was practically completed by December, 1905, although some work of minor importance was done in 1906. The principal contracts for the work were:

Dam.................. James Westwater.

Cement................The Kelley Island Lime and Transport Company.

Sluice-gates............Coffin Valve Company, and The Michigan Brass and Iron Works.

Clearing and grubbing...Hoover and Kinnear.

Roads.................. James Westwater, and The Buckeye Engineering and Construction Company.

Bridge................. Mt. Vernon Bridge Company.

THE SCIOTO RIVER PUMPING STATION AND WATER PURIFICATION WORKS.

The Scioto River pumping station and water purification works are located on the high ground on the north bank of the Scioto River, about 4.5 miles below the storage dam and about 1 mile above the old West Side Pumping Station. Plate II is a general plan of the works, and on Plate III is shown more in detail the arrangement of the several structures and the layout of the various conduits and pipe lines.

Briefly stated, the operation of the works is as follows: The raw water is drawn from the river through an intake and intake conduit to a raw-water suction well just south of the pumping station. From this well the water is pumped by low-lift pumps to the purification works where it is softened and filtered, passing finally through the filtered-water reservoirs and back to a filtered-water suction well just north of the pumping station. From this well the water is pumped by direct-service pumping machinery through two lines of 36-in. cast-iron pipe, about 4 900 ft. in length, to a point opposite the old West Side Pumping Station where connections are made with the existing distribution system.

Capacity of Works.—The pumping station and purification works are designed for extension to an ultimate net normal capacity of 40 000 000 gal. per 24 hours. At present the pumping station has a net normal capacity of 20 000 000 gal. per 24 hours, but the building is of sufficient size for equipment having the ultimate net normal capacity. The purification works at present have a net normal capacity of 30 000 000 gal. per 24 hours, but have been arranged so that extensions may readily be made.

Minor Structures.

Intake, Gate-House, and Intake Conduit.—The intake, on the river bank, consists of a low concrete head-wall provided with coarse screens, through which water is admitted to two 4-ft. concrete conduits connecting with the screen-wells in the gate-chamber. Passing through a double set of fine brass screens, 4 meshes per in., the water flows through a 5-ft. reinforced concrete intake conduit to the raw-water suction well. The gate-chamber is surmounted by a small brick gate-house, 17 ft. 4 in. square, in which are located the operating stands for controlling the sluice-gates and also a small hand traveling crane with an electric hoist for raising and lowering the screens and stop-planks.

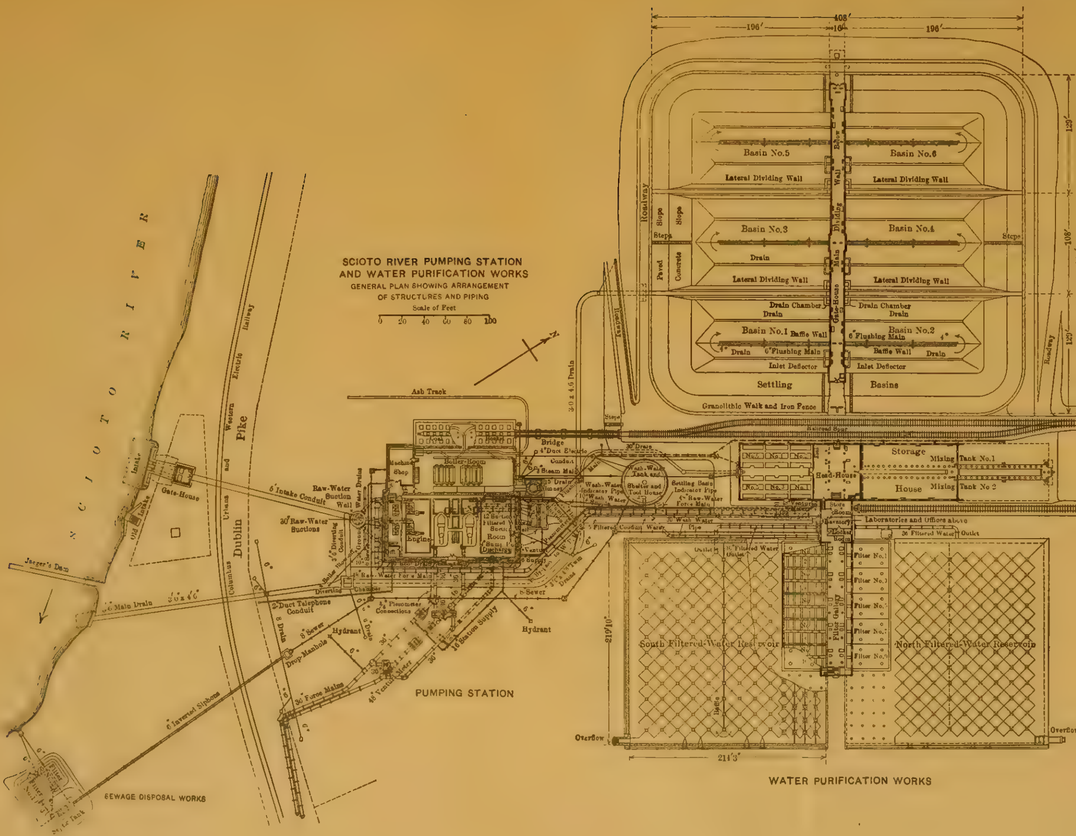
Raw-Water Suction Well, and Diverting Chamber.—The raw-water suction well is a circular concrete structure, 13 ft. in diameter inside and 34 ft. deep. From the well to the pumping station three 30-in. cast-iron suction pipes have been laid, but at present only two of them have been arranged to supply water to the low-lift pumping machinery. The level of the water in the suction well is shown by an indicator in the basement of the engine-room.

Connected with this well, also, are two lines of 24-in. perforated cast-iron pipe, each 24 ft. in length and located parallel to the south wall of the engine-room. These pipes are perforated with 1½-in. holes, 4 in. apart on centers, and are surrounded by layers of gravel screened to three different sizes. Under ordinary conditions, with low stages of water in the river, the sluice-gates on the inner ends of these pipes are closed, but, during periods of high water, it is possible to throttle the supply from the river and to open these gates and admit ground-water, the object being to lower the ground-water level as much as possible and thereby relieve, to a certain extent, the water pressure on the pipe gullets in the basement of the engine-room.

By reference to Plate III it will be seen that a drain from the settling basins passes down the east side of the pumping station and through a so-called diverting chamber. A 42-in. concrete diverting conduit connects the diverting chamber with the raw-water suction well. When one of the settling basins is drained for cleaning, the upper 10 or 12 ft. of water, which has been softened and settled, can be first drawn off, passing down the settling-basin drain and through the diverting chamber and diverting conduit to the raw-water suction well, from which it can be pumped back to the other compartments of the settling basins. The water remaining in the settling basin is then drained to the river. An overflow weir has been provided in the diverting chamber so that if the basin when full should be drained accidentally, before the gates in the diverting chamber are properly set, the water would be discharged over this weir and through the main drain to the river, thereby preventing the flooding of the grounds, the capacity of the weir being in excess of that of the settling-basin drain.

Filtered-Water Suction Well.—The filtered-water suction well is a rectangular concrete structure, 15 ft. wide, 24 ft. long, and 26 ft. 6 in. deep, divided into three separate wells, a 42-in. cast-iron suction pipe from each extending into the basement of the engine-room. At present

PLATE III.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



only two of the suction pipes are in service, the third being provided for a future pumping engine. Filtered water is delivered to the well, from a valve-chamber in the purification works, through a 5-ft. reinforced concrete filtered-water conduit, the valve-chamber in turn being connected with the filtered-water reservoirs by two lines of 36-in. cast-iron pipe. The suction well is tightly roofed over, but a hooded vent to the atmosphere has been provided. The water level in the well is shown by an indicator in the engine-room. A by-pass from the discharge pipes of the pumping engines connects with the suction well for the preliminary operation of the engines prior to placing them in regular service.

Railroad Spur and Bridge.—The pumping station and purification works are connected with the Pittsburg, Cincinnati, Chicago and St. Louis Railroad by a spur built on an embankment and terminating over the coal pocket. From the east embankment of the settling basins to the coal pocket the track is carried on a deck plate-girder bridge, 114 ft. 6 in. long, made up of four equal spans. The piers and abutments are of concrete.

Sewage Disposal Works.—The sewage from the pumping station and water purification works is cared for by a small disposal works on the bank of the river on the down-stream side of the low dam below the intake. As built, the works consisted of a septic tank and two intermittent sand filters. When the disposal works were designed it was known that they would be flooded by high water in the river, but it was expected that the damage could easily be repaired. The unusually high flood in the winter of 1908-09, however, demonstrated that it would be better not to attempt to repair the filters each time they might be damaged, and their use has been abandoned. In lieu of operating the filters, it is proposed to sterilize the effluent from the tank before discharging it into the river.

The Pumping Station.

Building.

Construction of Building.—The pumping station building, a plan and section of which are shown on Plates IV and V, covers an area of 147 ft. 6 in. by 152 ft. 8 in., and includes an engine-room, boiler-room, coal pocket, coal and ash tunnel, store-room, machine-shop, lavatory,

locker-room, and office. The substructure, throughout, is of concrete, reinforced with twisted steel rods where necessary.

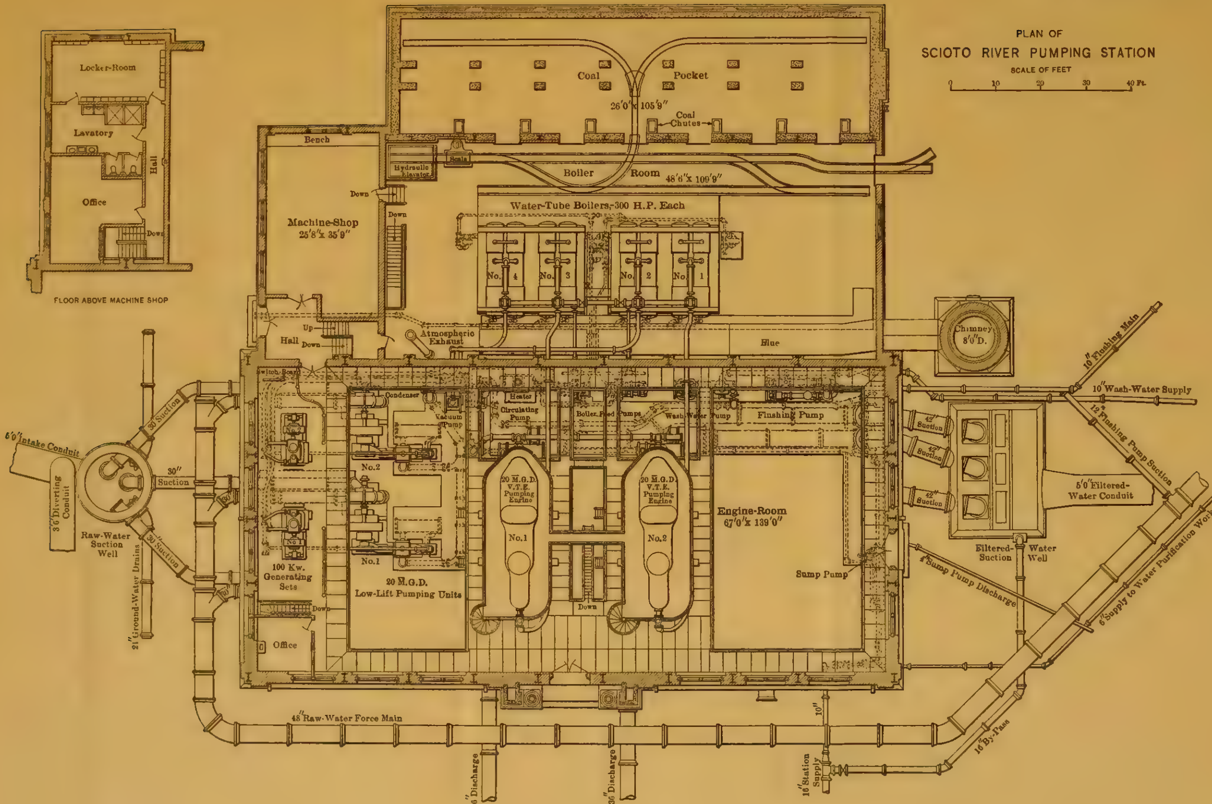
The superstructure, with the exception of the coal pocket, is of steel-frame construction, the roof trusses and crane runway girders being carried on steel columns. The walls are of brick masonry, faced outside with red pressed brick. The water-table, belt-courses, window-sills, main entrance, and similar trim, usually of cut stone, are of concrete, constructed in special moulds, with carefully finished surfaces, and present a very attractive appearance.

The engine-room roof is of slate laid on 3-in. hollow terra cotta tile supported on steel tees, which, in turn, are carried by the rafters and purlins. The under side of the tile is plastered with hard wall plaster and painted. The roof over the boiler-room and over the office, lavatory, and locker-rooms, consists of slabs of reinforced concrete, 4 in. thick, resting on the upper chords of the roof trusses and on the intermediate framing. On the concrete is laid three-ply roofing felt, bedded in hot asphalt, which in turn is protected by vitrified roofing tile, ¾ in. thick, also bedded in asphalt. Expansion joints in the concrete, flashed with corrugated copper, were made over each roof truss. The monitor over the boiler-room is of steel-frame construction, the walls being of expanded metal and plaster. The building is lighted throughout by electricity, and in the engine- and boiler-rooms, in addition to numerous incandescent lights, arc lights are used.

Engine-Room.—The engine-room basement is 67 ft. wide, 139 ft. long, and 17 ft. 6 in. in depth below the main gallery floor. The walls of the superstructure are set back 6¾ in. The total height of the room from the basement floor to the ridge of the roof is 91 ft. 7¾ in. The basement is floored only at the south end for a width of about 15 ft. where a small office, the generators, and the switchboard are located. A gallery, 5 ft. wide, extends around the four sides of the room, but, in front of the pumping engines, it is widened out to cover all the space between the engines and the main entrance. The pumping engines are reached at the rear by bridges connecting with the engine-room gallery. The walls of the superstructure are faced inside with pressed brick, the wainscot, 6 ft. 6 in. high, being of red vitrified brick, and the wall above of light-buff speckled brick. A ladder provides access to the crane cab.

The basement is reached by two stairways, one between the pumping

PLATE IV.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



PLAN OF
SCIOTO RIVER PUMPING STATION
SCALE OF FEET
0 10 20 30 40 Ft.

engines and the other at the south end of the room. Under ordinary conditions, the ground-water level is some 8 ft. or more below the basement floor, and on this account, and considering the character of the construction and the expense, the floor was not water-proofed. With long-continued, extreme, high water in the river, seldom likely to occur, the ground-water might rise to such an extent as to produce an upward pressure on the floor. To provide for this condition, however, openings, protected with gratings, have been left in the floor to relieve the pressure, and equipment has been provided for pumping out water which may find its way into the basement. The walls of the basement are painted.

Boiler-Room.—The boiler-room is about 48 ft. 6 in. wide, 109 ft. 9 in. long, and has a clear height of 29 ft. 2 in. to the lower chords of the roof trusses. The floor in front of the boilers, over the coal and ash tunnel, is of reinforced concrete, and, between the track and the boiler fronts, it is protected with checkered cast-iron floor-plates. The industrial railway in the boiler-room is made up of cast-plate track and switches. The walls of the room are lined with hard red brick. The monitor and roof trusses were designed to carry a coal conveyor, if it should be found desirable to install one.

The coal and ash tunnel below is 17 ft. 5 in. wide and 8 ft. 6 in. high in the clear, and provides ample room for the easy loading of coal and the removal of ashes. The tunnel is reached by a stairway at the south end of the boiler-room and also by a hydraulic elevator.

Coal Pocket.—The coal pocket, which is all above ground, is 26 ft. wide, about 105 ft. 9 in. long, and 12 ft. high in the clear, and provides storage for 800 tons of coal, or about 40 days' supply under present conditions. The walls are of concrete. The roof is of combined steel and reinforced concrete, the track rails being carried on steel I-beams and plate girders bedded in concrete. The thrust due to starting and stopping cars is taken up by the concrete columns and side-walls and by buttresses at the ends. Openings in the roof permit of using either side- or bottom-dumping cars. Openings in the floor admit coal to the chutes.

Machine-Shop and Rooms Above and Below.—The machine-shop, located just south of the boiler-room, is 25 ft. 8 in. wide and 35 ft. 9 in. long, and will be fitted up for small repair work with electrically-operated machine tools. The basement below the machine-shop, 24 ft.

8 in. wide and 47 ft. 11 in. long, is used as a store-room for miscellaneous supplies. Above the machine-shop is the main office, a lavatory with sanitary conveniences and shower baths, and a locker-room furnished with expanded-metal lockers.

Chimney.—The chimney is of radial brick construction, 8 ft. inside diameter at the top and 165 ft. 6 in. high, above the boiler-room floor. A fire-brick lining extends up about 42 ft. above the top of the flue opening. The foundation is of concrete, cored out to save material, and extends to a depth of 26 ft. 10 in. below the boiler-room floor, or to the same depth as the foundations of the building immediately adjoining. The superstructure of the chimney was built by H. R. Heinicke, Incorporated.

Machinery and Equipment.

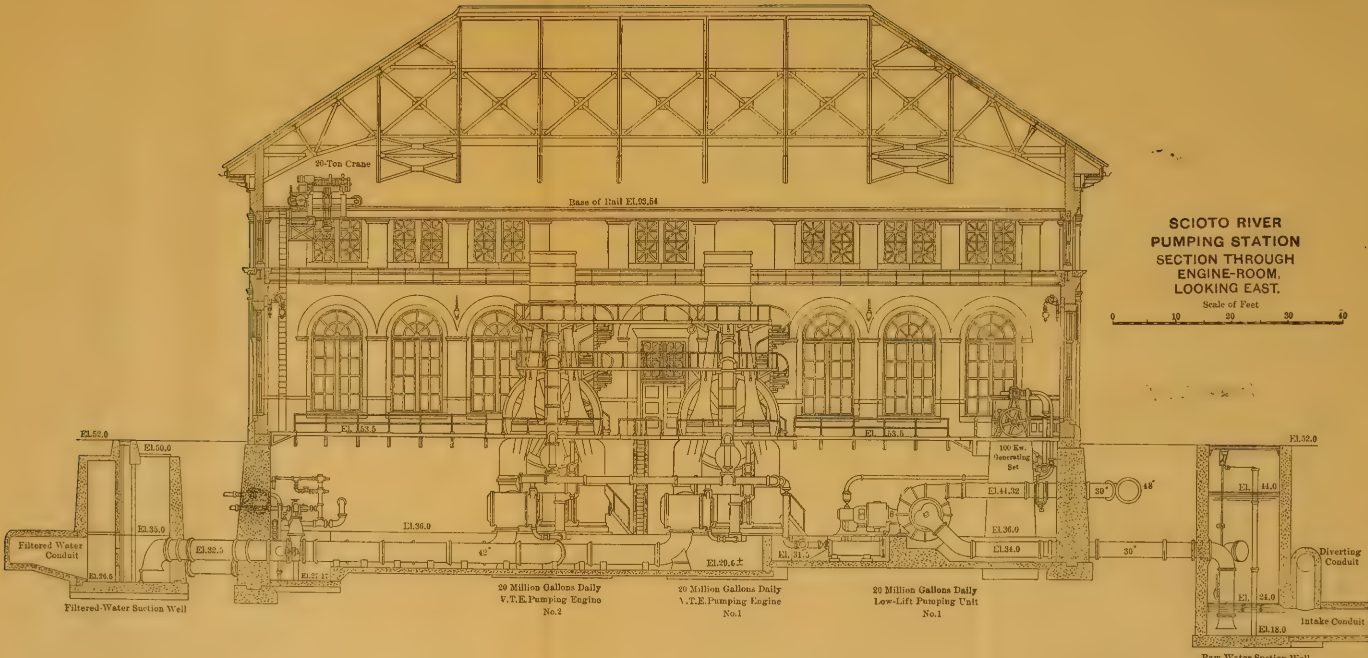
Pumping Engines.—For pumping filtered water to the City the present equipment includes two vertical, triple-expansion, pumping engines, built by the Holly Manufacturing Company, and operating on direct service. Space has been provided for a third engine. Each machine has a minimum capacity of 7 000 000 gal., a maximum capacity of 25 000 000 gal., and a normal capacity of 20 000 000 gal. per 24 hours, against a total head of 205 ft.

The pumping engines are of the single-A, box-frame type, the engine bed-plates being supported directly on the suction and discharge air chambers. The steam cylinders are 28, 54, and 80 in. and the water plungers 30½ in. in diameter. The stroke is 5 ft., and the piston speed 250 ft. per min. at normal capacity.

The suction pipe is 42 in. and the discharge 36 in. in diameter. Water is drawn through a surface condenser, taking the entire flow, into the suction valve-chambers, then passes through the pump cylinders and out through the discharge valve-chambers. The valve decks are vertical, of cast steel, the valves being screwed directly into the decks. An air compressor and vacuum pump is driven by the main engine, and provision has been made for the addition of a direct-connected feed pump.

Low-Lift Pumps.—For pumping raw water to the purification works, two low-lift pumping units have been installed, space being left for a third. Each unit consists of a single-suction, horizontal, Worthington, volute pump, with 26-in. suction and discharge nozzles, direct-connected to a 12½ and 30 by 17-in. horizontal, tandem-compound, con-

PLATE V.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



SCIOTO RIVER
PUMPING STATION
SECTION THROUGH
ENGINE-ROOM,
LOOKING EAST.

densing, four-valve, Fleming engine, and has a normal capacity of 20 000 000 gal. per 24 hours, against a total suction and discharge head of 43 ft., and a maximum capacity of 25 000 000 gal. per 24 hours, against a total head of 45 ft.

Generating Units.—The electrical equipment consists of two 100-kw., 250-volt, direct-current, Crocker-Wheeler generators, each direct-connected to an 11 and 21-in. by 12-in. vertical, cross-compound, Shepherd engine. The switch-board is of marble, and has two generator panels and one feeder panel, with the usual station instruments and with integrating watt meters on the lighting and power circuits which run to the purification works.

Flushing Pump.—For flushing out the settling basins, mixing tanks, and lime saturators of the purification works, raw water is used, and is supplied by a 12 and 20-in. by 15 by 15-in. horizontal, Worthington, compound, direct-acting pump with outside center-packed plungers. The pump has a normal capacity of 1 500 gal per min. against a total head of 140 ft., a minimum capacity of 250 gal. per min., and a maximum capacity of 2 000 gal. per min. The suction of the pump is connected with the 48-in. discharge pipe from the low-lift pumps supplying raw water to the purification works. An additional suction, extending to the bottom of the main gullet, has also been provided for use in case the automatic sump pump should be out of service, or should the condition arise whereby a relatively large quantity of water would find its way into the main gullet, due either to an accident, or to an excess of ground-water, as previously mentioned.

Wash-Water Pump.—Filtered water for washing the filters in the purification works is supplied to the wash-water tank by a 9 and 14-in. by 15 by 15-in. horizontal, Worthington, compound, direct-acting pump, having a normal capacity of 1 300 gal. per min. against a total head of 60 ft., and a maximum capacity of 1 600 gal. per min. The pump is controlled automatically by the level of the water in the wash-water tank, starting when the level drops to Elevation 86.5 and stopping when the level reaches Elevation 87.0. The suction is taken from a main connected with the suction pipe of one of the vertical, triple-expansion pumping engines.

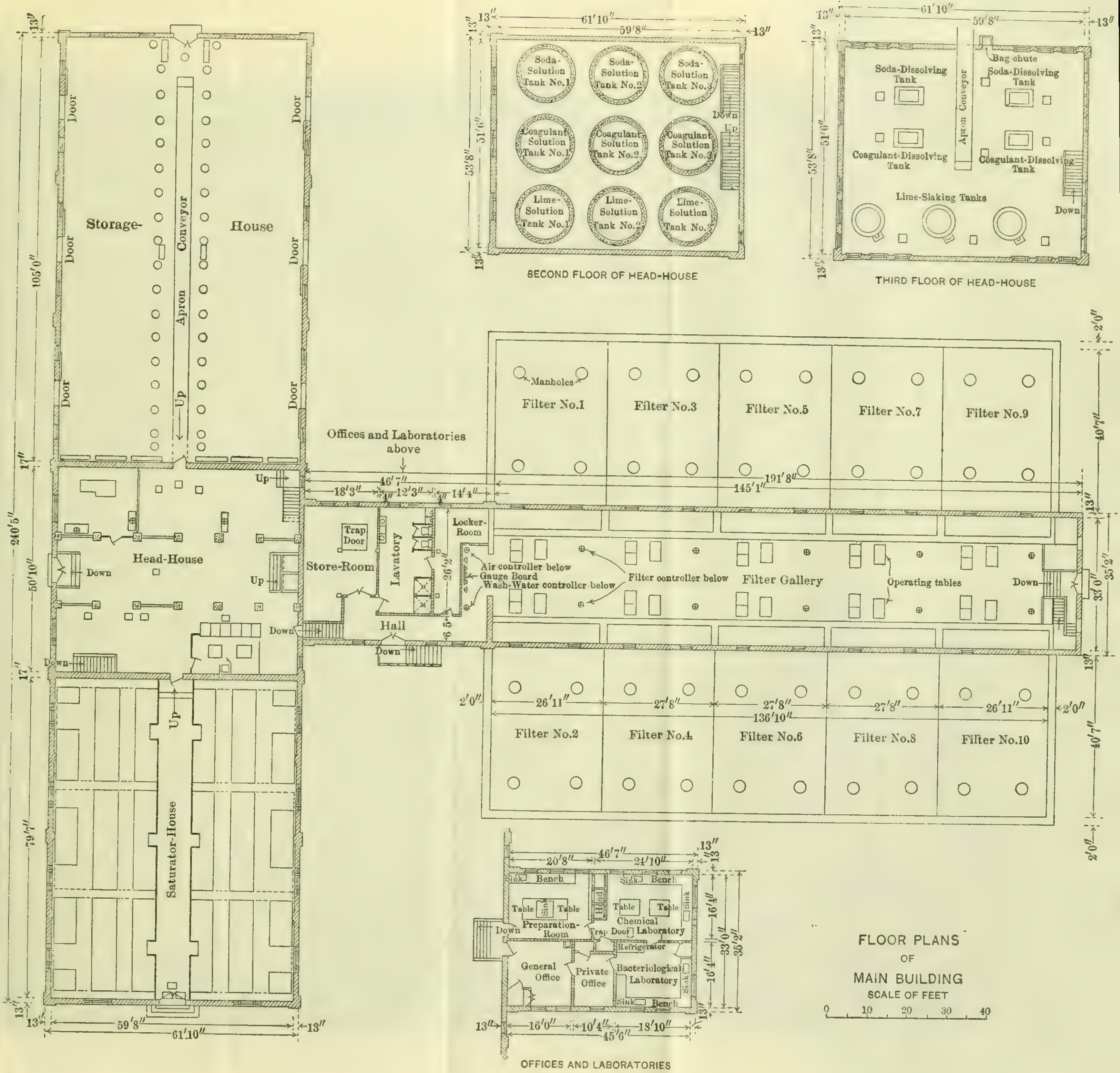
Boiler Feed Pumps.—The boilers are fed by two 12 and 7½-in. by 10-in. brass-fitted, Worthington pumps of the duplex, double-acting, outside-packed plunger type, each having a capacity of 150 gal. per

min., with water at 210° Fahr., against a steam pressure of 175 lb. per sq. in. Hot water is ordinarily supplied to the pumps from an open feed-water heater, but a separate cold-water supply is provided for use when the heater is out of service.

Independent Surface Condenser.—The exhaust steam from the low-lift pumping units, generating units, and flushing pump is piped to an independent Worthington surface condenser having 1 600 sq. ft. of cooling surface. The condensation is discharged by an 8 and 14-in. by 10-in. vertical, fly-wheel, suction, valveless, vacuum pump to the open feed-water heater. The circulating pump is a single-suction, horizontal, Worthington, volute pump, with 8-in. suction and 6-in. discharge nozzles, direct-connected to a vertical, single, 5 by 5-in. Blake engine. The circulating water is taken from a main connected with the 42-in. suction pipe of one of the vertical, triple-expansion pumping engines, and is returned to the suction pipe of the other pumping engine, the connections to both suction pipes being between the filtered-water suction well and the valves controlling the flow through the suction pipes.

Open Feed-Water Heater.—A Cochrane, open, feed-water heater, capable of raising the temperature of 50 000 lb. of water per hour from 100° to 210° Fahr., receives the condensation from the surface condensers of the vertical, triple-expansion pumping engines, from the independent surface condenser, and from the various steam separators and receivers, and also the exhaust steam from the wash-water pump, the independent circulating and vacuum pumps, and the boiler feed pumps. The feed-water heater serves as the hot well, and is raised from the floor of the engine-room basement so as to produce a head of about 4 ft. on the suction valves of the boiler feed pumps.

Sump Pump.—As the basement of the engine-room is too low to provide natural drainage at all times, a sump has been built, at the north end of the main gullet, which receives the water from the various drips and drains. On the bottom of the sump is placed a submerged 3-in., Worthington, vertical, volute pump having a capacity of 250 gal. per min. against a head of 20 ft. The pump is direct-connected to a 220-volt, enclosed, 5-h.p., Crocker-Wheeler motor, placed 2 ft. above the basement floor of the engine-room. The pump and motor operate automatically, starting when the level of the water reaches any desired point between Elevations 29.0 and 32.0, and stopping when the level



FLOOR PLANS OF MAIN BUILDING

drops to Elevation 27.0. The water is discharged into a drain leading to the river.

Boilers and Flue.—The boiler-room contains four 300-h.p., Babcock and Wilcox, horizontal, water-tube boilers, carrying steam at 160 lb. pressure. Space has been left, and the foundations built, for two additional boilers. At present the boilers are fitted with shaking grates, and are hand-fired, but the construction is such that mechanical stokers can be added when desired. The ash-pits are arranged with hopper bottoms below the level of the boiler-room floor, and are provided with chutes through which the ashes are discharged into ash cars in the coal and ash tunnel. Each boiler is provided with a hot-water meter on the feed pipe, and an automatic stop check-valve on the steam nozzle, in addition to the regular gate-valve.

The flue, the maximum section of which is 5 ft. wide and 12 ft. high, is of brick masonry, 12 in. thick, and is supported on steel I-beams. The floor of the flue is arched, and in the roof the brick-work is carried on steel tees. The draft is controlled by a damper and automatic damper regulator.

Steam Distribution.—In the steam supply lines a modified unit system of piping has been followed. The steam header is divided by double valves into two sections, the northerly section being over one battery of boilers and the southerly section over the other battery. Ordinarily, the valves are open. From one boiler in a battery a direct line is run to one vertical, triple-expansion, pumping engine, a branch connecting with the header, and from the other boiler a direct line is run to each pair consisting of one low-lift pumping unit and one generating unit, a branch from this line also connecting with the header. The other section of the header is similarly connected with the other pumping engine and low-lift pumping and generating units. Separate lines, run from each section of the header, supply steam to the boiler feed pumps, the lines being cross-connected, with double valves, in the engine-room. Steam for the flushing, wash-water, and independent circulating and vacuum pumps is taken from the lines supplying the boiler feed pumps.

Piping and Valves.—All cold-water pipes 4 in. in diameter and greater are of cast iron; if less than 4 in. they are of wrought iron, galvanized. Steam pipes greater than 2 in. are of wrought iron with rolled-steel flanges. Steam and hot water pipes less than 2 in., and the

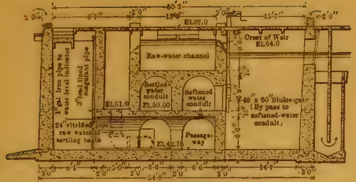
boiler feed pipes, are of brass. Exhaust pipes 6 in. and greater are of cast iron; if less than 6 in., they are of wrought iron. The drips from the exhaust separators are collected in two cylindrical tanks which, when full, automatically sound a high-water alarm. The tanks are then blown off to the sump at the end of the main gullet.

The gate-valves in the 30-in. discharge pipes of the low-lift pumps, and in the 42-in. suction and 36-in. discharge pipes of the pumping engines, are of the Coffin make, electrically-operated, but designed so that they may be opened or closed by hand if desired. No foot-valves or gate-valves have been placed on the suction pipes of the low-lift pumps, the valve in the discharge pipe being closed when a pump is not running. Each set of electrically-operated valves is controlled from a marble switch-board or panel fitted with controllers and indicators. The gate-valves on the steam lines and on water lines, other than those just mentioned, are of the Crane make, fitted with rising stems, those 2-in. and greater having outside screws and yokes. All valves except a few of the small ones are flanged.

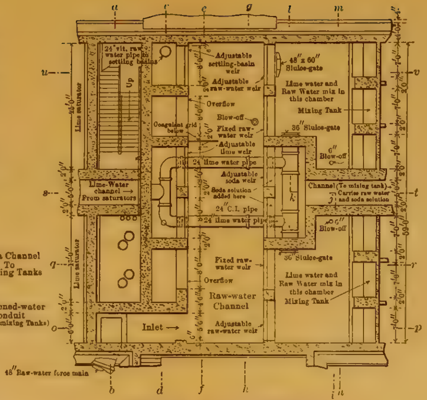
Water Meters.—All water is metered. The raw water pumped to the purification works passes through a 48-in. Venturi meter, an indicator and chart recorder being placed in the head-house of the purification works, and a register and manometer in the pumping station. All the filtered water pumped by the pumping engines passes through a 48-in. Venturi meter, the register and manometer for this meter also being in the pumping station. For supplying filtered water for the pumping station and purification works, a line connecting with the force mains below the Venturi meter is run back into the pumping station, where several branches are taken off, with a meter in each, supplying, respectively, the boiler feed make-up, the hydraulic elevator, the plumbing and other fixtures in the building, the purification works, and the wash-water tank. The line last mentioned provides another means of supplying filtered water to the wash-water tank, and is used when the wash-water pump is not running, the flow being controlled automatically by a Golden-Anderson, altitude valve.

Coal and Ash Handling Equipment.—For handling coal and ashes, a Hunt industrial railway has been installed in the coal pocket, boiler-room, and coal and ash tunnel. Ordinarily, the coal is drawn from the coal pocket, through chutes and hand-operated outlet-valves, into charging cars in the tunnel. The cars are raised by a direct-lift,

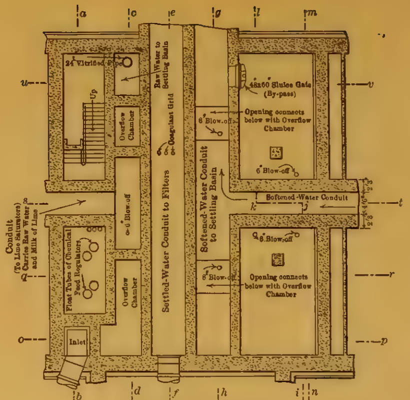
PLATE VII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



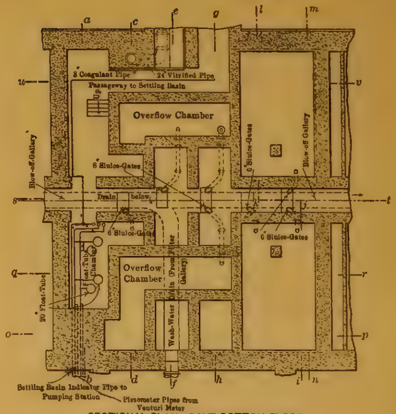
SECTION ON *u-v*



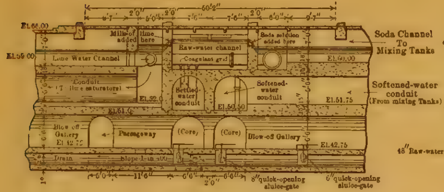
SECTIONAL PLAN BELOW FIRST FLOOR



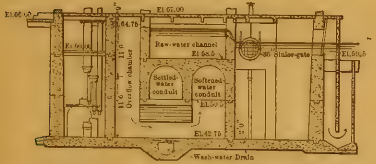
SECTIONAL PLAN THROUGH SETTLED
AND SOFTENED WATER CONDUITS



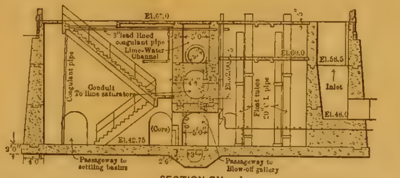
SECTIONAL PLAN ABOVE BOTTOM FLOOR



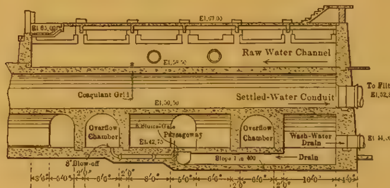
SECTION ON *s-t*



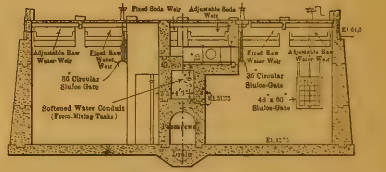
SECTION ON *q-r*



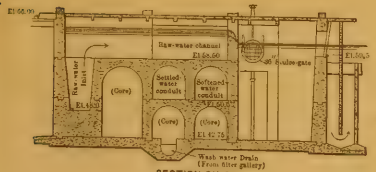
SECTION ON *a-b*



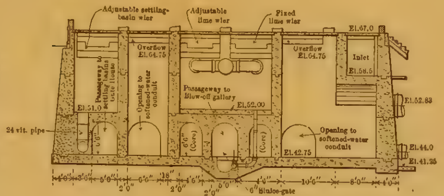
SECTION ON *e-f*



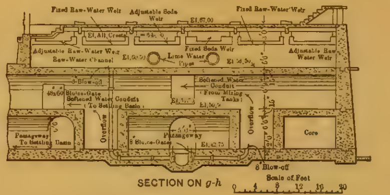
SECTION ON *i-j-k-l*



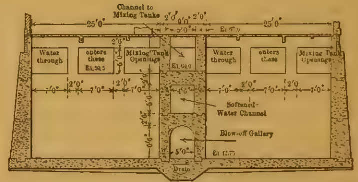
SECTION ON *o-p*



SECTION ON *c-d*



SECTION ON *g-h*



SECTION ON *m-n*

hydraulic elevator to the boiler-room floor, and then pass over a boiler-room track scale. At times, coal is also loaded by hand and run directly from the coal pocket into the boiler-room. The ashes are raked out into tip cars in the tunnel which are then taken out through the boiler-room and run over a track to the ash-dump where, for the present, they will be used in filling up an old gravel pit in front of the pumping station. The boiler-room, coal pocket, and tunnel have been designed so that an elevated coal bunker and conveyors can be added if desired, but, as the boilers at present have a total capacity of only 1 200 h.p., it was considered that the expense of this additional installation was hardly warranted.

Crane.—The engine-room is provided with a 20-ton, Case, electric crane having a span of 68 ft. 10 in. and a travel the full length of the room. The crane is fitted with 220-volt, slow-speed motors. With full load, the hoist has a speed of 12 ft., the trolley 100 ft., and the bridge 200 ft. per min., and a total lift of 57 ft.

The Water Purification Works.

In the description of the water purification works, which follows, it should be noted that the problem of purifying the water was not simply one of filtration, but of softening and filtration combined, and has required, therefore, not only mechanical filtration works, but softening works in addition. It should also be borne in mind that the Scioto River water is hard and at times highly turbid, and, in periods of flood, changes its character very rapidly from hour to hour, one especially troublesome feature being a very rapid increase in turbidity with a correspondingly rapid decrease in hardness. The works have been designed to meet these conditions, and it is on this account that various features of the work are somewhat different from ordinary standard practice.

Head-House.

The head-house, where some of the most important phases in the operation of the water purification works are controlled, is located practically in the center of the purification works. The raw water pumped from the river is first received in the substructure of this house, which is essentially a large gate-chamber.

The superstructure is a three-story building, on the first floor of which are located the devices for controlling the flow of water through

the substructure, the regulators for controlling the rate of application of the chemical solutions, the air compressor, and the motors for driving the stirring machinery of the lime saturators. Access is also had from this floor to the saturator-house, storage-house, offices and laboratories, and filter gallery, and also to the gate-house by means of an underground passageway. The second floor is given up entirely to nine large tanks in which the chemical solutions are stored, and the dissolving and slaking tanks are on the third floor. Sections through the head-house are shown on Fig. 9.

Substructure.—The substructure of the head-house, which is of more or less complicated design, and is built of concrete reinforced at points, is shown in detail on Plate VII.

The operation will be best understood by following the flow of the water. The raw water is first admitted to the raw-water channel, along each side of which are located the so-called head-house weirs. One portion of raw water passes over the lime weir, where milk of lime is added to it, and then flows to the lime saturators where it is converted into lime-water. Returning from the saturators the lime-water passes through two lime-water pipes into the two large raw-water chambers.

A second portion of raw water passes over the raw-water weirs into the two raw-water chambers just mentioned, where it mixes with the lime-water, the two then flowing into the mixing tanks.

A third portion of raw water passes over the soda weir, where a solution of soda ash is added, after which the raw water and soda solution flows out through the soda channel and thence into the mixing tanks at the points shown on Plate X, where it mixes with the raw water already treated with lime-water.

Returning from the mixing tanks, where the softening reactions largely take place, the water passes in the softened-water conduit back through the head-house and out to the settling basins, from which it returns through the head-house again, this time in the settled-water conduit, and passes to the filter gallery.

In addition to the weirs just mentioned, a fourth weir, known as the settling-basin weir, has been provided, over which, when desired, raw water from the raw-water channel can be discharged into a chamber and thence through a 24-in. pipe out through the main dividing wall of the settling basins, the object being to admit a small quantity of raw water to the softened water prior to filtration, in order to eliminate traces of caustic alkalinity.

Provision has also been made in the substructure of the head-house to by-pass the mixing tanks, as will be seen by referring to Plate VII, raw water being admitted directly from one of the raw-water chambers through a 4 by 5-ft. sluice-gate into the softened-water conduit leading

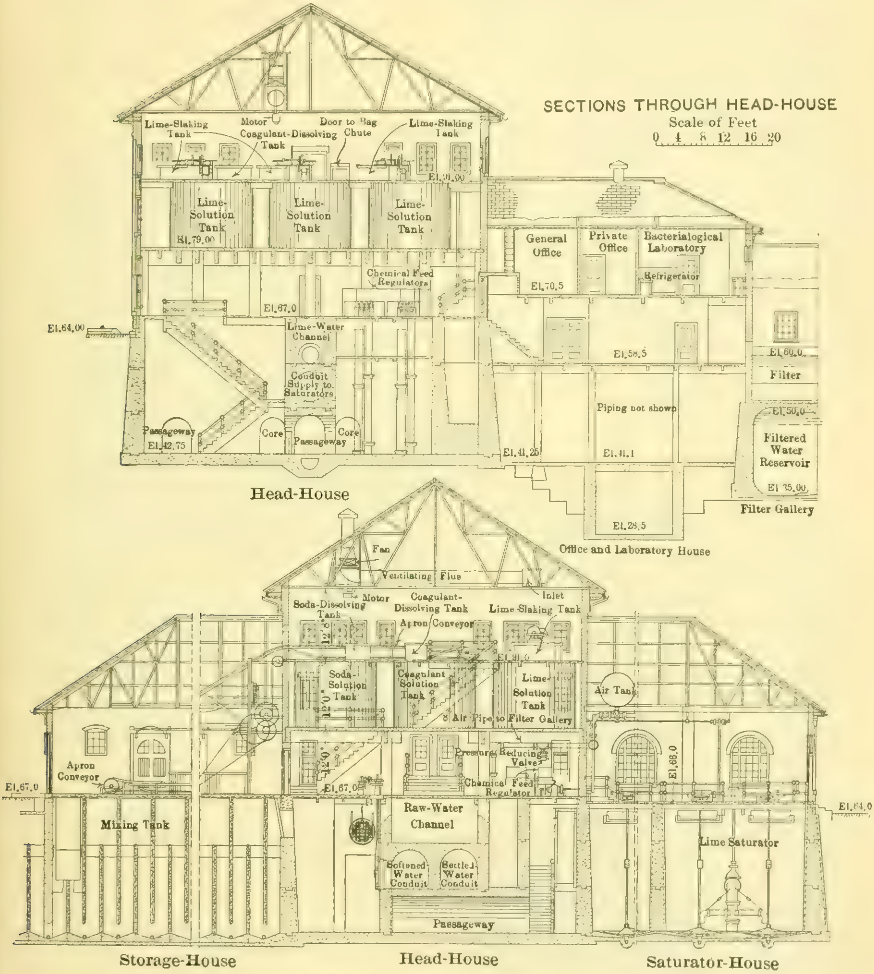


FIG. 9.

to the settling basins. Further, by a combination of stop-plank openings in the east end of the main dividing wall of the settling basins, as shown on Plate XI, it is possible to by-pass the settling basins, the water flowing from the softened-water conduit into the settled-water

conduit and thence to the filter gallery. In the latter case, coagulant would be added to the raw water through a grid placed in the settled-water conduit, as shown on Plate VII. It is probable that, if both mixing tanks were shut off, no attempt would be made to soften the water during such time as the tanks were out of service.

To prevent flooding the first floor of the head-house, if by accident the openings through which water would normally flow into the lime saturators and mixing tanks should be closed, two overflows have been placed on the south side of the raw-water channel over which the water would flow into two chambers connecting with the softened-water conduit and thence to the settling basins where it would be cared for by another set of overflows connecting with the drain running to the river. If, however, the settling basins were shut off from the head-house, the overflows last mentioned would be of no service, and, to prevent flooding, it would require that the filters be operated at such a rate as to care for all the raw water pumped into the head-house. This latter condition is seldom likely to arise, and then only for short periods of time, and, with a little added care on the part of the filter attendant, no trouble should be experienced.

The lower part of the substructure is reached from the first floor by a stairway, at the foot of which passageways lead to the blow-off galleries of the lime saturators and mixing tanks and to the spiral staircase in the main dividing wall of the settling basins.

Head-House Weirs.—With the exception of the settling-basin weir, the head-house weirs are adjustable, by movable flash-boards, from a fixed minimum to the maximum length. The settling-basin weir is adjustable for its full length. Each flash-board consists of a plate held on the outer end of an arm pivoted on a horizontal shaft, the arm, and thereby the plate, being raised or lowered by a rod extending up through the floor above. The total length of the head-house weirs is 56 ft. 10 in., but, of this length, it was expected that only 45 ft. 10 in., equal to 100%, would be in use at any one time. Each flash-board, with the exception of two which have a width of $2\frac{3}{4}$ in., has a width of $5\frac{1}{2}$ in., corresponding to 1% of the 45 ft. 10 in. The dimensions of the weirs as built are given in Table 7.

The rods operating the flash-board arms are held in guides, each guide being provided with a locking device, so that, after the weirs are properly adjusted for any condition of the raw water, the adjustment

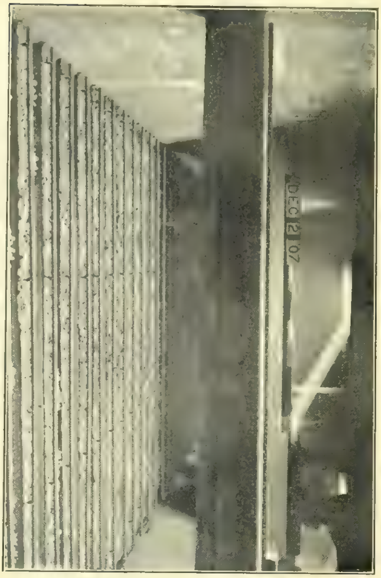


FIG. 1.—INTERIOR OF FILTER, SHOWING LATERAL AIR PIPES AND CONCRETE RIDGES BETWEEN STRAINER SLABS.

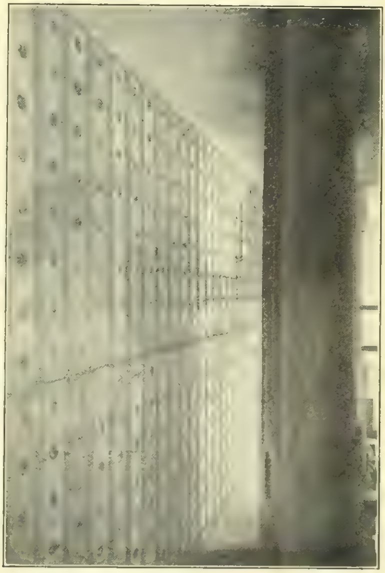


FIG. 2.—INTERIOR OF FILTER, SHOWING STRAINER SLABS SET IN PLACE.

FIG. 2.—INTERIOR OF FILTERED-WATER RESERVOIR: SIDE-WALL CONSTRUCTION.

cannot be changed without the knowledge of the person in responsible charge of the shift on duty. With a flow of 30 000 000 gal. per 24 hours, the head on the weirs would be about 0.45 ft., and about 0.55 ft. with a flow of 40 000 000 gal. per 24 hours.

TABLE 7.—DIMENSIONS OF HEAD-HOUSE WEIRS.

Net length in use, 45 ft. 10 in. = 100 per cent. 1% = 5½ in.

Weir.	Fixed Portion. Percentage of 45 ft. 10 in.	Fixed Portion. Length.	Adjustable Portion. Number of flash-boards.	Adjustable Portion. Length.	Total. Percentage of 45 ft. 10 in.	Total. Length.
Lime	11	5 ft. 0½ in.	13	5 ft. 11½ in.	24	11 ft. 0 in.
Raw water	50	22 ft. 11 in.	15	6 ft. 10½ in.	65	29 ft. 9½ in.
Soda	15	6 ft. 10½ in.	10	4 ft. 7 in.	25	11 ft. 5½ in.
Settling basin	0	0	10	4 ft. 7 in.	10	4 ft. 7 in.
Total	76	34 ft. 10 in.	48	22 ft. 0 in.	124	56 ft. 10 in.

When the works were designed it was thought that sufficient adjustment in the length of the several weirs had been provided to meet the varying conditions which were likely to arise, but it has been found, as a result of the operation of the works during the last year, that greater adjustment is necessary, and it is proposed to modify the construction accordingly.

Dissolving Tanks.—For dissolving the soda ash and coagulant, four tanks have been provided, two for each chemical. The tanks are of concrete, rectangular in plan, 5 ft. long, 3 ft. wide, and 2 ft. 8 in. deep. In the coagulant tanks the material to be dissolved is placed on a screen raised 3 in. above the floor of the tank, covering the whole width, and extending nearly to each end of the tank. At the inlet end a baffle extends from the top of the tank to the bottom of the screen, and at the outlet end another baffle extends from the bottom of the tank to within 8 in. of the top, above which is placed a screen. Water, which can be heated by steam if desired, is admitted back of the inlet baffle, passes down and under the horizontal screen, then up through the material to be dissolved and off through the screen over the outlet baffle. The outlet from the tank is also protected by a removable cylindrical screen, 3½ in. in diameter and 2 ft. 2 in. long. The baffles and screens

are of copper. In the soda tanks the arrangements are in general similar, except that the false bottom, originally provided, has been removed and replaced with an ejector-type heater to produce suitable circulation of the liquid in the tank.

Soda and Coagulant-Solution Tanks.—The soda and coagulant solutions are stored temporarily in six large cylindrical tanks, three for each solution. The tanks are of reinforced concrete, 12 ft. 6 in. in diameter and 11 ft. 5 in. deep. The piping from the dissolving tanks is arranged so that either or both of the dissolving tanks for one of the chemicals can discharge into any or all of the three solution tanks for the same chemical. Separate water connections are made for each solution tank, so that solutions of the required strength can be made up. Compressed air is used for agitation, to prevent stratification of the solutions.

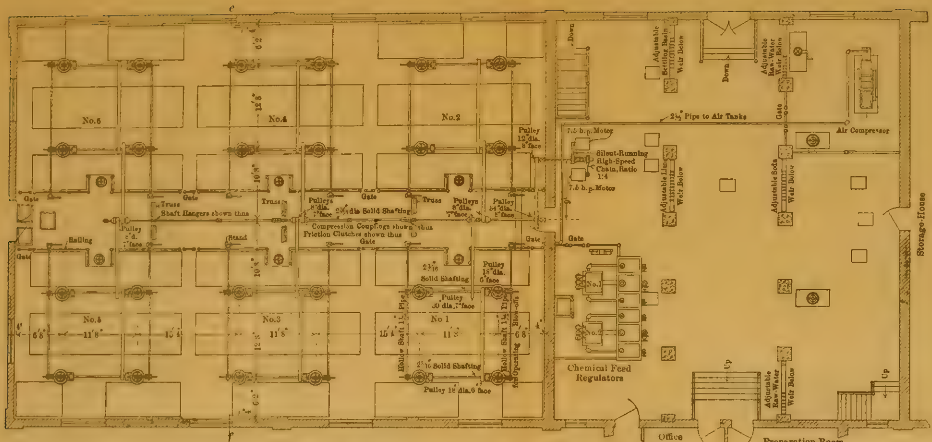
Lime-Slaking and Solution Tanks.—The three lime-slaking tanks are of reinforced concrete, and are 6 ft. in diameter and 2 ft. 8 in. deep. The lime and water are stirred, during the process of slaking, by vertical rakes carried on horizontal arms and driven through gearing and a silent-running high-speed chain by a 220-volt, 1½-h.p. Crocker-Wheeler, variable-speed motor. After the lime is slaked, the tank is discharged into a so-called lime-solution tank below, where, by the addition of more water, milk of lime of the required strength is made up. There are three reinforced concrete lime-solution tanks, each 12 ft. 6 in. in diameter and 11 ft. 5 in. deep. The milk of lime is agitated by a vertical shaft and horizontal paddles driven from the motor which operates the stirring rakes in the slaking tank.

Chemical Feed Regulators.—The chemical solutions are fed automatically in proportion to the quantity of raw water pumped into the head-house, this being accomplished by a specially designed chemical feed regulator, provided in duplicate, and operated by the difference in head on the up-stream end and throat of the 48-in. Venturi meter located in the raw-water force main just outside of the head-house.

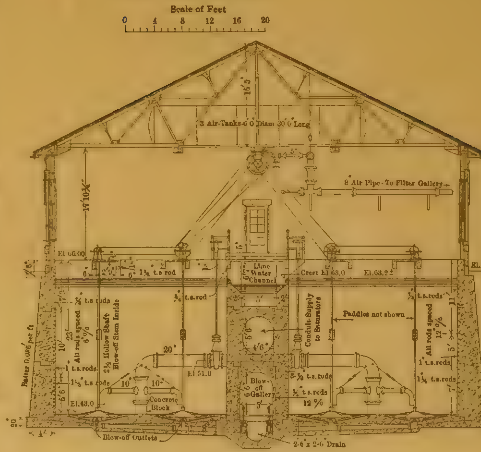
Air Equipment.—Air, for use in washing the filters, is furnished by a Bury air compressor, placed on the first floor of the head-house. It has a rated capacity of 100 cu. ft. of free air per min. compressed to a gauge pressure of 60 lb. per sq. in., and is driven by a 15-h.p., 220-volt, Crocker-Wheeler motor. The compressed air, prior to use in washing, is stored in three tanks supported in the roof trusses of the saturator-

PLATE IX.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

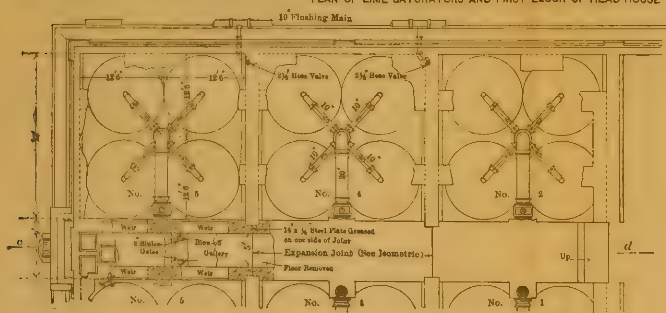
LIME SATURATORS



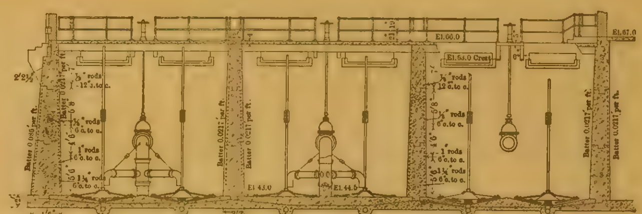
PLAN OF LIME SATURATORS AND FIRST ELOOR OF HEAD-HOUSE



CROSS-SECTION



PLAN OF PART OF LIME SATURATORS. (STIRRING MACHINERY NOT SHOWN)



LONGITUDIUAL SECTION, STIRRING MACHINERY REMOVED

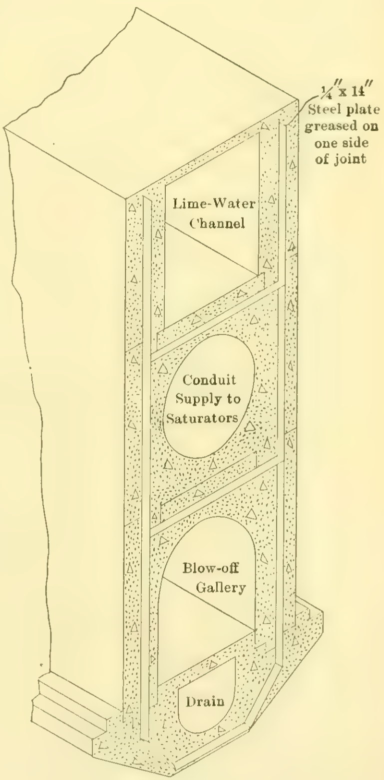
house, each tank being 6 ft. in diameter and 30 ft. long, and built of $\frac{1}{4}$-in. riveted steel plate. An 8-in. air pipe runs from the air tanks to the filter gallery, and, in this line, as it passes through the head-house, is placed a Foster pressure-reducing valve, which maintains a practically constant pressure of from 2 to 4 lb. per sq. in. on the outlet side as may be desired. The air tanks are of sufficient capacity to permit one filter being washed about every $1\frac{3}{4}$ hours, for about 3 min., at a maximum rate of 3 cu. ft. per sq. ft. per min.

Saturator-House.

The six lime saturators are in a wing of the main buildings just south of the head-house, and are shown in detail on Plate IX. Raw water, to which a solution or suspension of milk of lime has been added in the head-house, is brought out through the middle conduit in the main dividing wall, and passes into each saturator through a 20-in. cast-iron pipe, branching into four 10-in. pipes. Rising slowly through the saturators, lime-water is produced and flows over the weirs into the lime-water channel and thence back to the head-house and into the two large raw-water chambers, where it mixes with the bulk of the raw water which is to be softened.

The saturators were designed for a maximum upward velocity of about 10 ft. per hour and to produce a total of about 6 750 000 gal. of lime-water per 24 hours.

Construction of Tanks.—The saturators are of concrete, heavily reinforced, each tank being 25 ft. square and 20 ft. deep. The bottom of each saturator is in



ISOMETRIC SECTIONAL ELEVATION
SHOWING EXPANSION JOINT.

Fig. 10.

the form of four inverted cones, in the center of each of which is a 6-in. outlet for blowing off sludge. These outlets connect with pipes running to the drain below the floor of the blow-off gallery, the end of each blow-off pipe being provided with an 8-in., quick-opening, circular sluice-gate with lever handle. Each 6-in. outlet is fitted with a loose disk or valve, operated from the top of the main dividing wall, so that the four inverted cones may be blown off separately.

Stirring Machinery.—To prevent the deposition of the lime, and to insure thorough mixing of the lime solution with the water, the liquid in the saturator is agitated slightly. The agitators, of which there are four to each saturator, consist, at the bottom, of conical hoods, 4 ft. in diameter, of ¼-in. steel plate, and carrying two arms or paddles. The paddles are set up about 2 in. from the surface of the conical bottom, and revolve slowly at a speed varying from 3 to 4½ rev. per min., as may be desired. Paddles are also provided on the vertical shafts.

The agitators are driven by vertical hollow shafts of 2-in. wrought-iron pipe, which in turn derive their motion through bevel gearing and countershafts. A line shaft, hung from the lower chord of the roof trusses, is belted to the countershafts and to a jack-shaft. The agitators for each saturator are controlled by friction clutches on the line shaft. The jack-shaft is driven through a silent-running, high-speed, Morse chain by a 7½-h.p., variable-speed, 220-volt, Crocker-Wheeler motor. The motors for driving the machinery are in duplicate, and are located in the head-house.

Storage-House and Mixing Tanks.

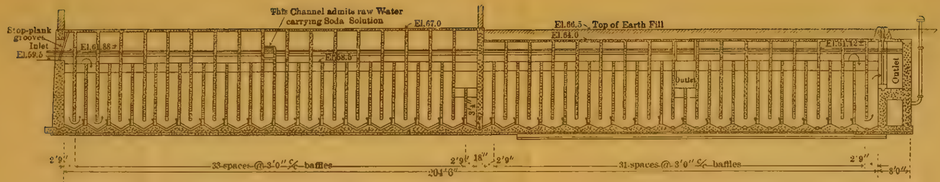
The storage-house and mixing tanks, the details of the latter being shown on Plate X, are in a wing of the main building just north of the head-house, the southerly portion of the mixing tanks being directly below the storage-house. There is a railroad spur on each side of the storage-house, the doors being spaced so that six cars may be set at one time for unloading.

Storage-House.—The storage-house consists of one large room, 59 ft. 8 in. wide and 105 ft. long, and is used for the storage of the chemicals used in the softening and purification processes. The floor of the storage-house, which serves also as the roof for that portion of the mixing tanks situated below, is designed for a live load of 500 lb. per

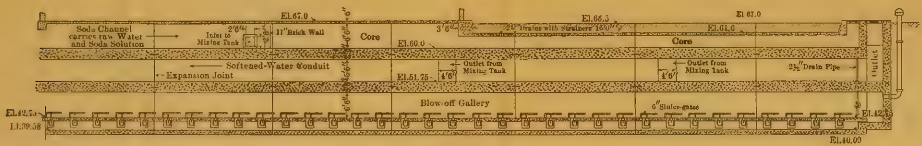
PLATE X.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

MIXING TANKS

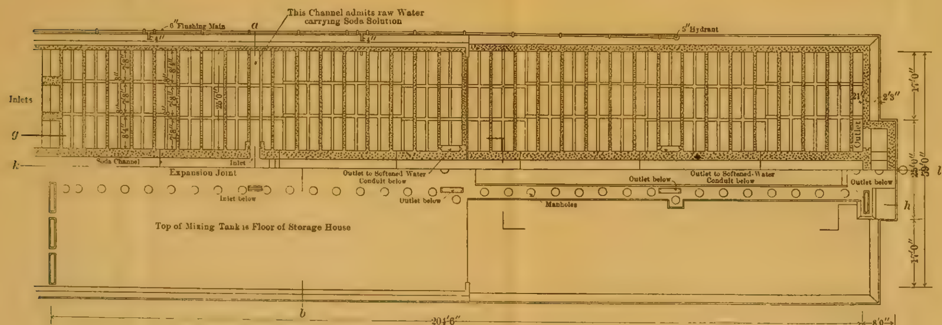
Scale of Feet
0 10 20 30 40



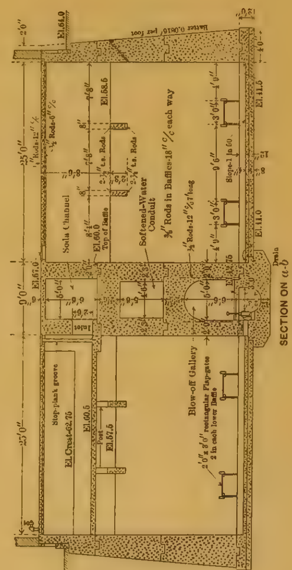
SECTION ON *g-h*



SECTION ON *k-l*

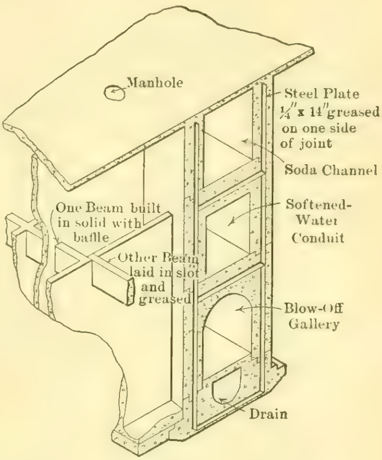


SECTIONAL PLAN



sq. ft., and, on this basis, allowing space for the unloading and handling of the chemicals, the house has a maximum storage capacity of 900 tons, or about 20 carload lots.

The chemicals are handled in bags, each containing a net weight of 100 lb. From the floor of the storage-house the bags are transported by a Jeffrey apron conveyor to the third floor of the head-house, where the solutions are made up. The conveyor, which is in the center of the storage-house and extends nearly its full length, is driven by an 18-h.p., Crocker-Wheeler enclosed motor, and has a maximum carrying capacity of 12 bags per min. when running at a speed of 50 ft. per min.



ISOMETRIC SHOWING EXPANSION JOINT

FIG. 11.

Mixing Tanks.—The two mixing tanks, in which the softening reactions largely take place, are of peculiar construction, as they are highly baffled, the arrangement of the baffles being such as to tend to prevent sedimentation and keep the solids in suspension rather than to assist sedimentation. The operation of the tanks is as follows:

Raw water, to which lime-water has been added in the two large raw-water chambers in the head-house, enters the tanks at the surface at the southerly end. Passing vertically downward, it is deflected under the first baffle, then rises vertically, passing over the second baffle, then downward again, and so on. Another portion of raw water, to which the soda solution has been added in the head-house, flows out through the channel in the upper part of the dividing wall, and is then deflected laterally into two small channels over the down-stream edges of which it falls into the raw water to which the lime-water has already been added. From this point on, the raw water, which has now been treated with both lime and soda ash, flows through the tanks to the outlets, the mixture of the raw water with the lime-water and soda solution being ensured by the high degree of baffling.

Under normal conditions, when treating 30 000 000 gal. per 24 hours, a period of about 1 hour will be required for the water to pass through the mixing tanks. Provision has also been made so that the water may be drawn off, if desired, when it has passed either one-half or three-quarters of the way through the tanks. When treating 30 000 000 gal. per 24 hours the mean velocity through the tanks is about 0.37 ft. per sec. and about 0.5 ft. per sec. when treating 40 000 000 gal. per 24 hours.

As designed, the tanks were intended to be operated in parallel only, but it has been found desirable at times to operate them in series, that is, to pass the water up through one tank and back through the other. This can be accomplished by the use of temporary bulkheads, but changes in the construction are contemplated so that this method of operation may be easily permitted when desired.

The tanks, which are constructed throughout of concrete, reinforced where necessary, are each 204 ft. 6 in. long and 25 ft. wide, and have a water depth of a little more than 20 ft., depending on the quantity of water passing through. The baffles are 6 in. thick, and are 3 ft. from center to center, the 68 chambers or pockets formed by the lower baffles being drained by 6-in., quick-opening sluice-gates which discharge into the drain in the bottom of the main dividing wall.

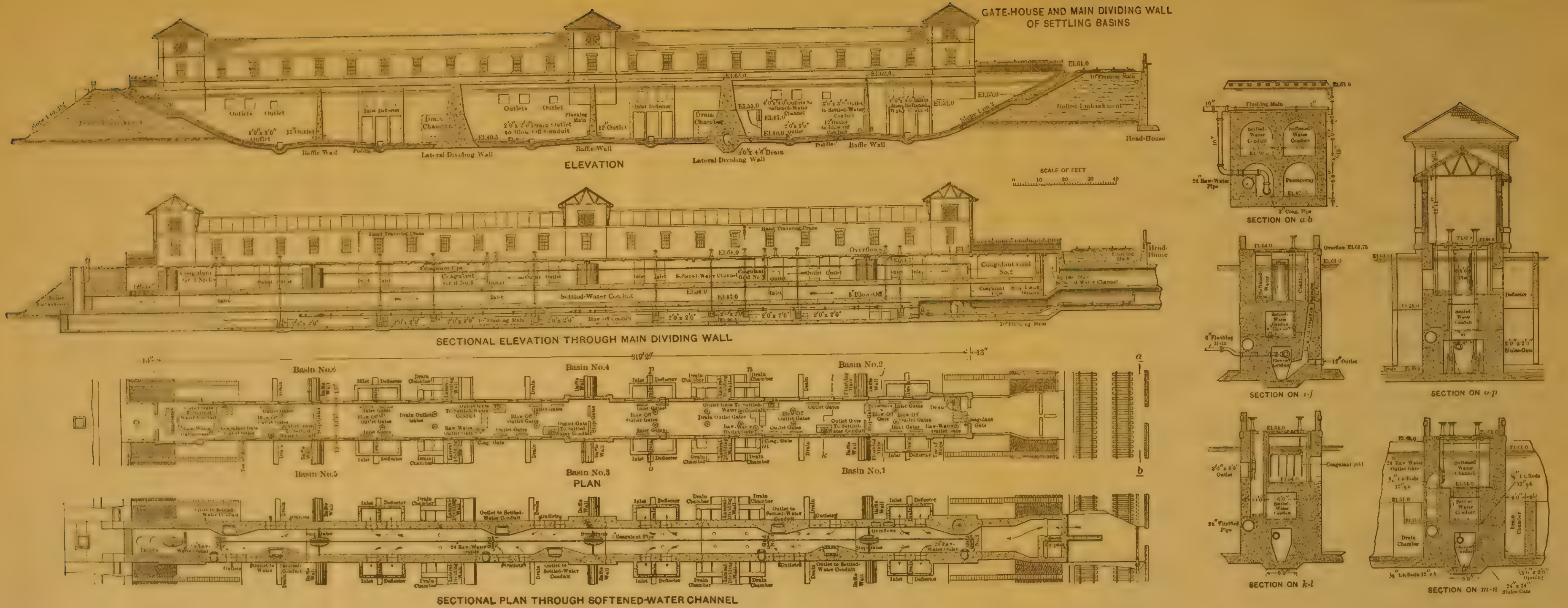
As the baffles were not designed to withstand water pressure on one side only, each lower baffle is fitted with two 2 by 3-ft. rectangular flap-gates, hung on bronze-mounted hinges and swinging in openings through these baffles, the gates being heavy enough to keep the opening closed when water is flowing through the tanks under the ordinary conditions of service, but swinging open under a slight difference of head on the two sides of the baffle caused by the opening of the 6-in. blow-off gates.

The dividing wall is of heavy cored construction, the upper passage or soda channel supplying raw water and soda solution to the tanks, as previously mentioned. The middle passage or softened-water conduit carries softened water from the outlets of the tanks back to the head-house and to the settling basins. The lower passage or blow-off gallery provides access to the blow-off gates.

In order to keep the floor of the storage-house free of operating stands, and also to provide large openings, stop-planks, instead of sluice-gates, are used for controlling the flow of water at the inlets and outlets of the tanks.

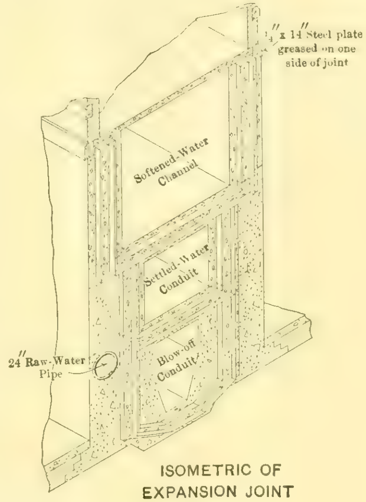
PLATE XI.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

GATE-HOUSE AND MAIN DIVIDING WALL OF SETTLING BASINS



Settling Basins.

The general plan of the six settling basins is shown on Plate III, and Plate XI shows the details of the embankments, walls, and gate-house. The six basins have a total capacity of approximately 15 000 000 gal., equivalent to 12 hours' subsidence when the purification works are running at their normal capacity. The water varies from 19 to 21 ft. in depth, the average being about 20 ft. The basins are operated on the continuous plan, that is, water is admitted continuously at one end and drawn off at the other. The normal water line is at Elevation 61.0, or 1 ft. above the normal water line on the filters. Should pumping cease, it would be possible to draw the basins down to about Elevation 58.0 before it would become necessary to shut down the filters, due to lack of water. The volume thus drawn would be about 2 700 000 gal., a quantity sufficient to supply the filters for a little more than 2 hours.



ISOMETRIC OF EXPANSION JOINT

FIG. 12.

Embankments and Floors.—The embankments are composed of a mixture of gravel and loamy clay, in 6-in. layers, and well rolled. For water-tightness, dependence is placed on a lining of clay puddle, 18 in. thick on the bottom and lower part of the slope, and 12 in. thick on the upper part. The puddle, which was mixed rather wet and in the proportion of 1 volume of clay to 2 volumes of gravel, was placed in 6-in. layers and rolled with a grooved roller until hard. On the bottom and lower part of the slope the puddle is protected with a 6-in. concrete floor, and on the upper part of the slope with limestone paving, 10 in. thick, bedded on 2 ft. of screened gravel.

Lateral Dividing and Baffle Walls.—The lateral dividing and baffle walls are of concrete. The lateral dividing walls have a gravity section, and the baffle walls are stable against wind pressure when the basins are empty, but neither of the walls was designed to resist ice pressure. In the foundation under the dividing wall separating Basins Nos. 1 and 3, a 3 ft. by 4 ft. 6-in. drain has been built, connecting the

blow-off conduit in the main dividing wall with the drain running to the diverting chamber and to the river.

Main Dividing Wall.—The main dividing wall is also of concrete, and its rather complex design is illustrated on Plate XI. The wall serves, not only as a dividing wall, but also to control the flow of water to the several basins and the return to the filters. The operation of the basins may be best followed by referring to Plates III and XI.

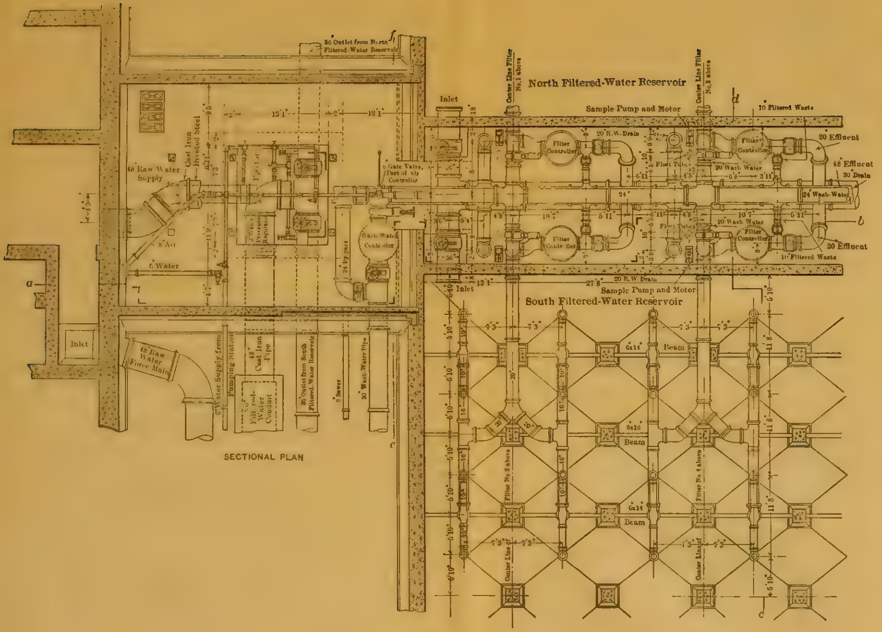
Softened water, on its return from the mixing tanks, passes through the head-house and is admitted to the softened-water channel at the east end of the main dividing wall. From this channel the water flows out through openings into Basins Nos. 1 and 2, passes under deflectors in order to interrupt surface currents, around the baffle walls, and back through other openings into the channel. The water then follows a similar course through the other basins until it reaches the west end of the channel, where it passes down through openings into the settled-water conduit and thence back through the head-house to the filter gallery. The course of the water is controlled by wooden gates, held in grooves and operated from the floor above.

It is also possible to operate the basins in a different way, namely, to admit water to all of them at once, instead of to each set of two basins in series, as just described, this being accomplished by raising all the stop-gates in the softened-water channel except those at the extreme west end, and by closing all the outlets from the basins to the channel. Settled water would then be drawn off from each basin through an opening connecting with the settled-water conduit.

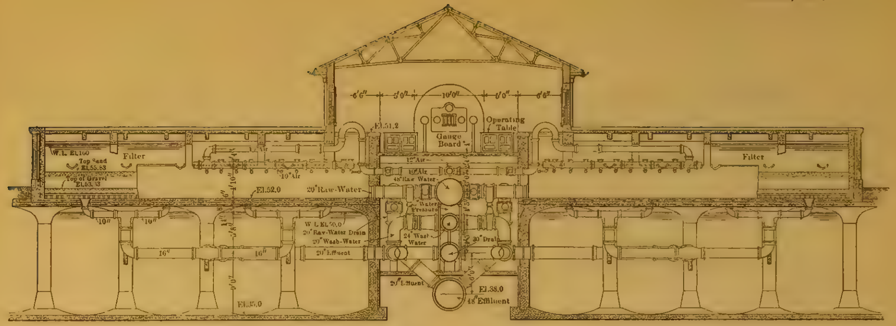
A 3-in., lead-lined, iron pipe extends practically the full length of the softened-water channel, with grids located so that the coagulant can be added just before the water enters each set of two basins, or just after it leaves the last two basins on its way to the filters. The grids are of copper pipe with special composition valves and fittings, and are perforated with ¼-in. holes, 18 in. from center to center each way.

It has been found desirable to be able to add coagulant at two different places at the same time, and, while this can be accomplished with the work as built, it is impossible to tell just how much coagulant is being added at each grid. To overcome this difficulty, a rearrangement of the coagulant piping is to be made, so that the discharge from each grid can be measured accurately.

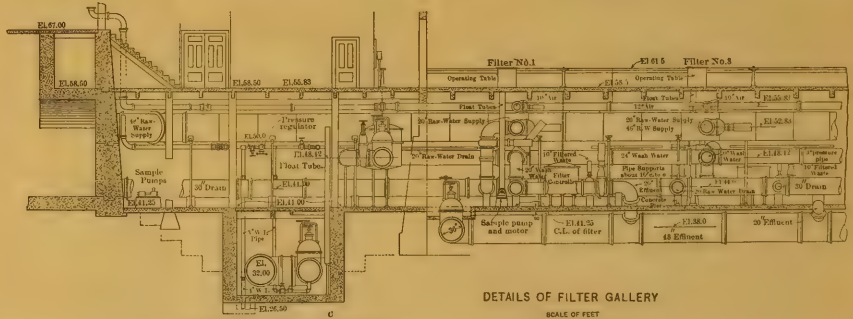
PLATE XII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
[redacted]
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



SECTIONAL PLAN



SECTION ON *c-d*



SECTIONAL ELEVATION ON *a-b*

DETAILS OF FILTER GALLERY

SCALE OF FEET

As mentioned previously, provision has been made for admitting small quantities of raw water to the softened water, prior to filtration, in order to eliminate traces of caustic alkalinity. A 24-in. vitrified raw-water pipe, connecting with the adjustable settling-basin weir in the head-house, is embedded in and extends the full length of the main dividing wall and has four outlets, controlled by sluice-gates, for admitting water to the softened-water channel. At each expansion joint in the wall, a short length of riveted steel pipe was used in place of vitrified pipe.

The lower conduit or channel in the main dividing wall serves as a blow-off drain for emptying the basins. This blow-off conduit is also connected with the drain chambers in the basins, so that the upper 10 or 12 ft. of water in a basin can first be drawn off to the diverting chamber and raw-water suction well, and re-pumped to the other basins before the basin is drained out at the bottom. A 10-in. flushing main is hung from the top of the blow-off conduit, a branch line with several 2½-in. hose-valves extending out into each basin.

Gate-House.—The main dividing wall is surmounted by a long brick gate-house extending practically the full length of the dividing wall. In addition to the doors at each end, the gate-house may be reached by a spiral staircase and underground passageway connecting with the passageway at the foot of the stairway in the substructure of the head-house. For raising and lowering the wooden gates controlling the flow of water in the softened-water channel, two 1-ton, Case, hand, traveling cranes have been provided.

Filter Gallery.

The filter gallery is in the wing of the main building east of the head-house, with the filter tanks ranged on either side of the gallery and supported on the roof of the filtered-water reservoirs. Between the filters there is a reinforced concrete operating floor, below which, and between the walls of the filtered-water reservoirs, is the pipe gallery.

Filter Tanks.—The present installation includes ten filters, the details of which are shown on Plate XIII, each having a normal capacity of 3 000 000 gal. per 24 hours. The filter tanks are of concrete heavily reinforced, each being constructed as a monolith. Their inside dimensions are 26 ft. 2 in. wide, 46 ft. 8 in. long, and 8 ft. 10½

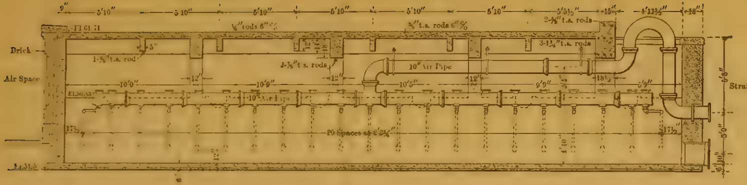
in. deep at the center. Each has a net filtering area of 1 088.9 sq. ft., or 0.025 acre. The filters are designed on the basis of a normal rate of filtration of 2 gal. per sq. ft. per min., but can be operated at a rate 50% greater than the normal, if desired.

Extending down the middle of each tank there is a central gutter, 1 ft. 10 in. wide and 4 ft. 10 in. deep, which divides the filter into two separate parts. On each side of and connecting with the central gutter there are six lateral gutters, 7 ft. 9 in. from center to center. The edges of these lateral gutters, for a distance of 3 ft. 2 in. back from the central gutter, are raised so that no water will flow over them at these points, thereby reducing the quantity of wash-water which the lateral gutters will have to carry, and tending to produce a more uniform rate of discharge of the wash-water from the surface of the filter.

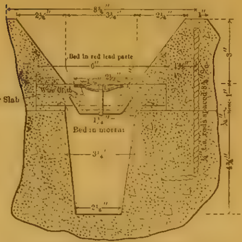
Strainer System.—The strainer system of each filter is divided into eight units, the water passages of each unit consisting of a series of lateral channels connecting with a main collector and built monolithic with the floor of the tank. The strainers are held in slabs of fine concrete, the slabs being constructed in separate moulds and then bedded in mortar on the walls separating the water passages. The strainer slabs are held down by prisms or ridges of concrete, built in place, lapping over the edges of the strainer slabs and anchored to the floor of the tank by bent twisted-steel rods. The strainers consist of circular brass plates, No. 16, B. & S. gauge, depressed at the center and pierced with 45 holes, $\frac{1}{16}$ in. in diameter. Each strainer is bedded in a thin paste of red lead, and is held in place by a brass bolt and a brass clip, the clip in turn being held in the strainer slab. There are 2 048 strainers in each filter, $8\frac{3}{4}$ in. from center to center each way, the total area of the holes in the strainer plates in one filter amounting to 1.96 sq. ft., or 0.18% of the filtering area. The strainer system was designed for the application of wash-water at an average rate of 8 gal. per sq. ft. per min. under a net head of about 3 ft., but a maximum rate of 10 gal. per sq. ft. per min. can be obtained, if desired. The effluent piping below the filter is arranged so that the friction loss from the outlet at the center of each of the eight units to the beginning of the main effluent pipe is the same.

Air System.—In addition to water, air can be used in washing the filters. A main air pipe of cast iron, 10 in. in diameter, is supported above the central gutter, and, from outlets in the bottom, branch pipes

PLATE XIII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

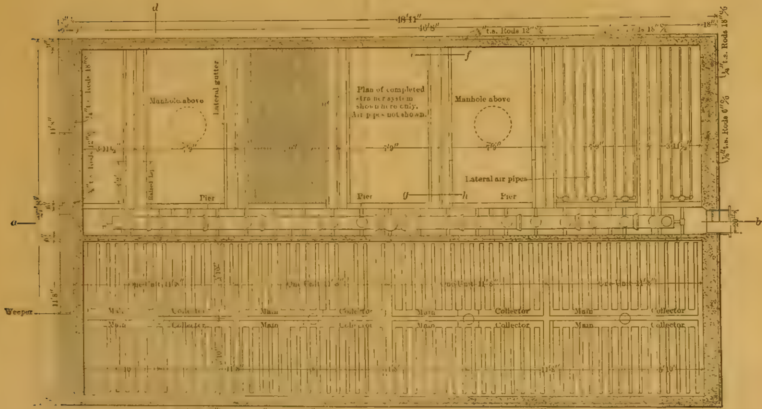


SECTION ON *a-b*



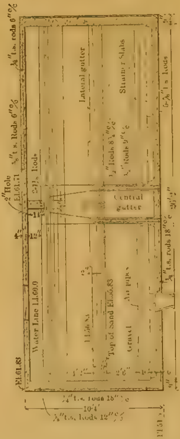
SECTION THROUGH LATERAL COLLECTOR OF STRAINER SYSTEM

SCALE OF FEET



Note: Section is taken below lateral gutters. Air pipes and strainer slabs not shown.

SECTIONAL PLAN OF FILTER



SECTION ON *c-d*

DETAILS OF FILTERS

extend down through the walls of the central gutter and connect with the lateral air pipes in the filter. These lateral pipes, which are 8¾ in. from center to center and are supported above the ridges holding down the strainer slabs, are 1 in. in outside diameter, and are drilled on the under side with ⅛-in. holes 8¾ in. from center to center. All the air pipes except the 10-in. main are of brass. The air system was designed for a maximum rate of 3 cu. ft. of free air per sq. ft. per min.

Filtering Materials.—The filter gravel, which was screened and washed, is placed in four layers, graded in size, the coarsest, No. 1, being at the bottom. The sizes and thicknesses of the layers of gravel are given in Table 8. The material was brought from Cape May, N. J.

TABLE 8.—FILTER GRAVEL.

	Size.	Thickness.
No. 1	½ in. to 1 in.	2 in.
No. 2	¼ in. to ½ in.	2 in.
No. 3	⅛ in. to ¼ in.	3 in.
No. 4	$\frac{1}{16}$ in. to ⅛ in.	3 in.

The filter sand, which is supported by the filter gravel, has a total thickness of 2 ft. 6 in. The material is a crushed sandstone, screened and washed, and was obtained from the Millwood White Sand Company, of Millwood, Ohio. The analysis of the sand is given in Table 9.

TABLE 9.—FILTER SAND.

Effective size	0.415 mm.
Uniformity coefficient	1.36
Amount finer than 0.2 mm	0.15 per cent.
Amount finer than 0.25 mm	0.52 per cent.
Amount finer than 0.8 mm	95.0 + per cent.
Amount finer than 1.0 mm	98.5 + per cent.
Specific gravity	2.63
Silica (SiO_2)	94.5 per cent.
Lime (CaO), finer than 0.36 mm	1.43 per cent.
Iron (Fe_2O_3)	0.5 per cent.

Pipe Gallery and Operating Floor.—The arrangement of the pipe gallery is shown on Plate XII. The main piping is of cast iron, with the exception of the 48-in. raw-water supply, which is of riveted steel. It might be well to state that in the filter gallery the pipes supplying water to the filters for filtration are called raw-water supply pipes, although normally they carry softened, settled water. This name was adopted solely in order to avoid confusion in the operation of the

filters, and, for general purposes, was considered better than the term influent. The small piping is of wrought-iron, brass, or lead, depending on the service. The valves used in operating the filters are all flanged, and are operated hydraulically.

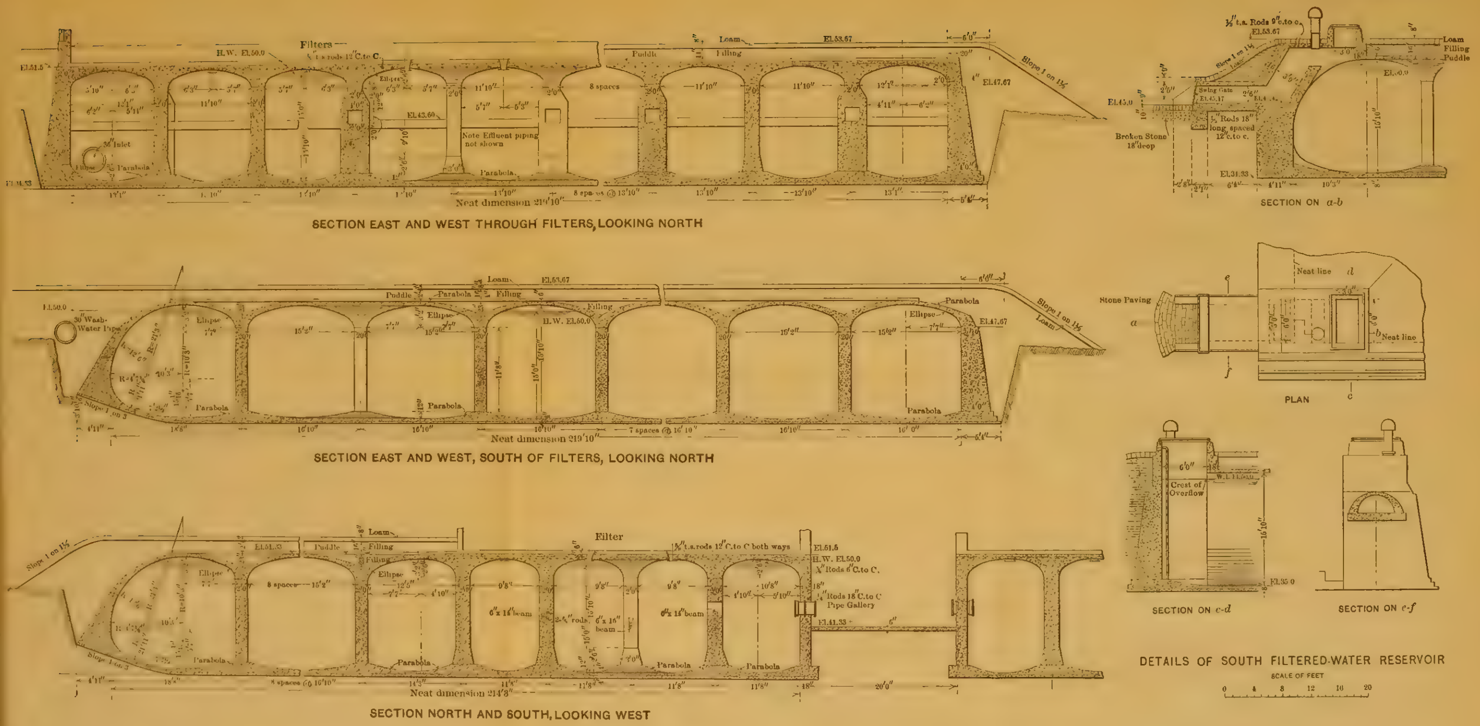
On the operating floor in front of each filter there is a marble operating table fitted with four-way cocks, with extension stems and lever handles, for controlling the opening and closing of the hydraulic valves. An indicator in front of each lever handle shows the position of the valve, whether open, closed, or partly open. A loss-of-head gauge, mounted on the table, shows the elevation of the water on the filter and in the effluent pipe, and also the difference between the two, or the loss of head. Samples of the settled water and of the filtered water can be pumped by two small electrically-driven centrifugal pumps into the bowl on the operating table.

The discharge of each filter is controlled by a filter controller which maintains automatically a uniform rate of filtration. The controller is of the closed type, is self-contained, requiring no auxiliary device for its operation, was designed especially for the Columbus works, and operates under a net loss of head of about 1 ft. The controller is adjustable by means of an operating stand on the floor above, and has a capacity ranging from a minimum of 1 000 000 to a maximum of 4 500 000 gal. per 24 hours.

Water for washing the filters is supplied from an elevated tank located between the pumping station and the purification works. The rate of application of the wash-water can be controlled by a wash-water controller located in the main wash-water pipe at the west end of the pipe gallery, or it can be controlled by hand at the operating table. The controller is similar in design to the filter controller, and has a maximum capacity of 16 000 000 gal. per 24 hours, with a net loss of head of about 1 ft.; the dial on the operating stand, however, is graduated to read the rate of application of the wash-water to the filters in gallons per square foot per minute.

The equipment for supplying air for washing the filters has already been mentioned. The rate of application of the air wash is controlled by a gate-valve in the main air pipe at the west end of the gallery. By means of the pressure-reducing valve, a constant pressure is maintained on the up-stream side of the gate-valve, and, by opening or closing the main valve, from the operating stand on the floor above,

PLATE XIV.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



DETAILS OF SOUTH FILTERED-WATER RESERVOIR

the flow of air is controlled. The dial on the operating stand is graduated to indicate the rate of application of the air to the filters in cubic feet per square foot per minute.

At the west end of the filter gallery there is a gauge board on which is mounted a recording gauge showing the level of the water in the wash-water tank, a recording gauge showing the pressure of the air in the air tanks in the saturator-house, and a gauge showing the pressure of the air in the main air pipe on the down-stream side of the air-controlling valve. Mounted on this board, also, there are four glass tubes through which samples of the river water, softened water, settled water, and filtered water can be observed, being supplied by small pumps located in the pipe gallery below. These pumps also supply samples of the four kinds of water to the laboratories above.

Filtered-Water Reservoirs.

To compensate for the hourly and also daily variation in the rate of pumping into the distribution system, the city being on direct service, as previously mentioned, two covered filtered-water reservoirs have been constructed. The reservoirs, throughout, are of concrete, the construction being of the groined-arch type, in general similar to that adopted for covered reservoirs elsewhere. Each reservoir is 219 ft. 10 in. long, 214 ft. 3 in. wide, and 15 ft. 10 in. deep, and, with water 15 ft. in depth, has a capacity of approximately 5 000 000 gal., the two having a total of 10 000 000 gal., equal to about 8 hours' supply when the purification works are operated at a rate of 30 000 000 gal. per 24 hours. The plan of the reservoirs is shown on Plate III and longitudinal and cross-sections of the south reservoir on Plate XIV.

Floor.—The floor, which has a minimum thickness of 8 in. midway between the piers, was built in two layers, the lower layer having a thickness of 4 in. throughout. The joints were made on the diagonal lines between the piers, the joints in the upper layer lapping over those in the lower layer by about 3 or 4 in.

Walls.—The walls adjacent to and forming the sides of the pipe gallery are built with plumb faces, and are reinforced both vertically and longitudinally. The east wall of each reservoir is plumb on the inside and battered on the outside, and is of such design that it will serve as a future dividing wall when the works are extended. The remaining length of wall, except immediately under the west walls

of Filters Nos. 1 and 2, has a section similar to one-half of the cross-section of a large aqueduct.

Vaulting.—Over about three-fourths of the area of the reservoirs the groined arches have a clear span of 15 ft. 2 in., a rise of 3 ft. 2 in., and a thickness of 6 in. at the crown, the piers being 20 in. square. Over the remaining fourth of the area, the span of the arches is reduced, being 9 ft. 8 in. one way and 11 ft. 10 in. the other, with piers 2 ft. square. The vaulting over this area is level on top, is 8 in. thick at the crown of the arch, and is reinforced with $\frac{5}{8}$-in., square, twisted-steel rods 12 in. from center to center each way. The filter tanks are built on top of this portion of the vaulting, the piers being located so as to come under the walls and central gutters of the tanks, where the loads are the heaviest. The vaulting is covered with a 4-in. layer of clay puddle, with 2 ft. of filling above.

Baffle Walls.—The baffle wall in each reservoir is 6 in. thick, reinforced with $\frac{3}{8}$-in. square twisted-steel rods 18 in. from center to center each way, and extends from the floor to the vaulting. The walls are keyed into the piers, the section between each two adjacent piers being built as a monolith.

Pipe Connections and Overflows.—Filtered water is admitted to each reservoir at the west end of the pipe gallery, and is drawn off on the opposite side of the baffle wall from the inlet, into a 36-in. filtered-water pipe. The two filtered-water pipes are brought together in a valve chamber where they connect with a 48-in. pipe opening into the 5-ft. filtered-water conduit running to the filtered-water suction well north of the pumping station.

Each reservoir is provided with an overflow, the crest being at Elevation 50.0, or 10 ft. below the normal water line in the filters.

Offices and Laboratories.

That portion of the wing of the main building east of the head-house and lying between the head-house and the filter gallery is two stories in height, with a basement below, and at this point the main entrance to the purification works is located. The first floor is on the same level as the floor of the filter gallery, and contains a locker-room, a lavatory, and a storeroom. In the storeroom is located a machine for producing gas for use in the laboratories. The general office, a private office, the bacteriological and chemical laboratories, and a preparation-

FIG. 1. INTERIOR OF FILTER GALLERY.

FIG. 2.—VIEW OF CHEMICAL MIXING ROOM.

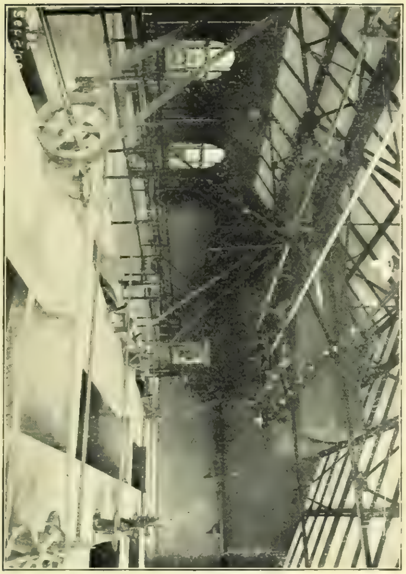


FIG. 3. INTERIOR OF LIME SATURATOR HOUSE.

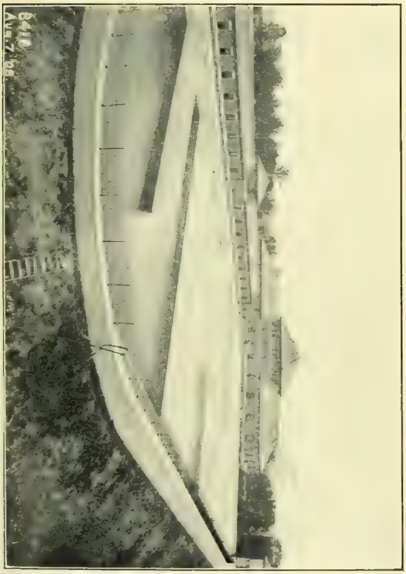


FIG. 4. VIEW OF SETTLING BASINS.

room, are on the second floor. The basement is in reality the west end of the pipe gallery, and through it pass the pipe lines connecting the substructure of the head-house with the filter gallery.

Wash-Water Tank, Shelter, and Tool-House.

Midway between the pumping station and saturator-house there is an elevated tank, with a shelter and tool-house below.

Wash-Water Tank.—The tank is 42 ft. in diameter, inside, and 11 ft. deep, and with water 10 ft. in depth has a capacity of 104 000 gal., sufficient to wash two filters, one immediately after the other, at a rate of 8 gal. per sq. ft. per min. for a period of 7 min. each, making allowance for the quantity supplied by the wash-water pump during the period of washing. The floor of the tank is at Elevation 77.0, about 24 ft. above the ground and 20 ft. 2 in. above the top of the gutters in the filters. The tank is of reinforced concrete, with 12-in. walls, and is supported on concrete columns.

Shelter and Tool-House.—The space below the tank is divided into two floors; the upper floor contains a storeroom, and also a lavatory and locker-room for the use of the laboring force employed in unloading coal and chemicals, cleaning the intake screens and settling basins, cutting grass, etc. The ground floor is used as a small stable, provision being made for keeping two horses; this floor is used also as a store-house for tools.

Construction of Buildings.

The walls of the main building and gate-house are of brick, faced outside with red pressed brick. In the gate-house, and in the saturator-house, storage-house, and third floor of the head-house of the main building, the walls are lined inside with hard red brick; in the other parts of the main building the walls are finished with hard wall plaster. The ceilings in the offices, laboratories, preparation-room, and third floor of the head-house are plastered on expanded metal fastened to the lower chords of the roof trusses. The water-tables, belt-courses, window-sills, lintels, and copings are of concrete of the same character as that used in the pumping station.

The floors, columns, and stairways are of reinforced concrete. The roof trusses are all of steel, the covering being of slate laid on 3-in., hollow, terra cotta tile. In the gate-house, saturator-house, storage-house, and filter gallery, the tile is plastered on the under side. The

buildings are lighted throughout with electricity, and the main building is heated with steam.

Concrete.

In the construction of the work, concrete, both plain and reinforced, was used extensively, the total quantity in the pumping station, purification works, and adjacent structures amounting to 39 560 cu. yd. The average price paid for the above amount was $7.27 per cu. yd. The relative volumes of cement, sand, and ballast in each mixture of concrete, and the corresponding character of work in which the mixture was used, were as follows:

1 : 2 : 4.—Water-tables, belt-courses, window-sills, lintels, etc.; filter, solution, dissolving, and wash-water tanks; reinforced floors, roofs, stairways, and steps.

1 : 2½ : 5½.—Columns in buildings and piers of wash-water tank; filtered-water reservoirs, lime saturators, mixing tanks, and substructure of head-house; settling basins, except lateral dividing and baffle walls; walls in general, conduits, and miscellaneous small structures.

1 : 3 : 7.—Lateral dividing and baffle walls of settling basins; footings, and foundations for machinery and chimney.

The specifications permitted the engineer to change the relative volumes of the sand and ballast in each mixture, while keeping the aggregate of the two the same, and this was sometimes done, but in general the proportions as given above were used. Ordinarily, the concrete was mixed very wet.

The ballast was screened into three sizes: No. 1, ¼ to ¾-in.; No. 2, ¾ to 1½-in.; and No. 3, 1½ to 3-in. In ordinary work a mixture of the three sizes was used, but, in a considerable amount of the reinforced work, the No. 3 ballast was omitted, and frequently only the No. 1 ballast was used, particularly in thin vertical work and in the lower parts of beams and horizontal reinforced work, in order to insure a good bedding of the square, twisted-steel rods.

Expansion joints were built throughout the work where necessary. Where subject to the action of water which had been treated with lime and soda, the expansion joint consisted of a tongue and groove in the concrete, with a steel plate bedded and anchored on one side of the joint and greased on the other; in other places the tongue and groove only was used.

Connections to City.

From the pumping station the purified water is pumped to the city through two lines of 36-in. cast-iron force mains to a point opposite the old West Side Pumping Station, where connections are made with the existing distribution system, a Venturi meter being placed on each connection. A 36-in. branch also connects with the suction wells at the old pumping station, so that filtered water can be pumped from this station in case of a shut-down at the new pumping station, the two 36-in. force mains being so arranged at the new pumping station that they can be operated as gravity mains from the water purification works. While it is not planned to run the old station, this method of operation was very serviceable in furnishing the city with a partial supply of filtered water before the new pumping station was entirely ready for use.

The main approach to the new works from the city is by the Dublin Pike, a country road, in which the force mains are laid. As the road was in bad condition, and as one or two stretches were sometimes under water during periods of flood in the river, the opportunity was taken to improve it at the time the force mains were laid, by regrading it, macadamizing the surface, and fencing it along the embankment portions.

Cost of Work.

Table 10 gives the total cost of the work in such detail that further description is hardly needed, and Table 11 gives the unit costs of the main features of the work. No attempt has been made to distribute the cost of engineering over the several parts of the work, as it is believed that the figures are of greater value as presented than if they included a percentage for engineering.

Contractors and Progress of Work.

The first bond issue was authorized in November, 1904, and the preparation of the first drawings and specifications was commenced shortly after. The purification works were placed under contract in June, 1905, the machinery and equipment for the pumping station in September, 1905, the pumping station and connections in July, 1906, and the force mains connecting with the city in October, 1907. Raw water was first pumped to the purification works on July 2d, 1908, and

TABLE 10.—COST OF SCIOTO RIVER PUMPING STATION AND WATER PURIFICATION WORKS AND WORK CONNECTED THEREWITH.

LAND.....58 acres				$48 410
RAILROAD SPUR TO PURIFICATION WORKS AND PUMPING STATION.				
Track.....2 760 lin. ft.		$5 740		
Culvert, 6 by 6-ft.....50 lin. ft.		810		
Track Scales.				
Foundations	$1 060			
Scales and track	1 860	2 920		
Bridge.....115 lin. ft.				
Substructure	500			
Superstructure	3 530	4 030	$13 500	
ROADS, WALKS, GRADING, AND DRAINAGE OF GROUNDS.				
Roads, walks, and grading		7 620		
Drainage of grounds		770	8 390	
RAW-WATER SUPPLY CONNECTIONS FROM RIVER TO PUMPING STATION.				
Intake, river to gate-house		2 600		
Gate-House.				
Substructure.....14 400 cu. ft.	5 360			
Superstructure.....5 160 cu. ft.	1 230			
Screening equipment	1 740	8 330		
Intake conduit, 5-ft.....180 lin. ft.		3 540		
Raw-water suction well		1 440		
30-in. suction pipes to pumping station, 110 lin. ft.		3 720		
Ground-water drains		1 250	20 880	
FILTERED-WATER SUPPLY CONNECTIONS FROM PURIFICATION WORKS TO PUMPING STATION.				
5-ft. Filtered-water conduit.....300 lin. ft.		3 540		
Filtered-water suction well		2 760		
42-in. suction pipes to pumping station..50 lin. ft.		1 050	7 350	
48-IN. RAW-WATER FORCE MAIN AND METER.				
48-in. Force main.....550 lin. ft.		7 800		
48-in. Venturi meter and vault		3 670	11 470	
MAIN DRAIN AND BRANCHES.				
Drains.				
Branch drain from settling basins, 3-ft. by 4 ft. 6-in.....250 lin. ft.	1 440			
Branch drain from saturator house, 30-in., 190 lin. ft	1 440			
Branch drain, boiler blow-off, 4-in..150 lin. ft.	60			
Main drain, twin section, 3-ft. by 4 ft. 6-in., to diverting chamber.....350 lin. ft.	3 410			
Main drain, 3-ft. by 4 ft. 6-in., diverting chamber to river outlet.....280 lin. ft.	2 020			
River outlet	310	8 680		
Diverting Chamber and Conduit.				
Diverting chamber	1 410			
Diverting conduit, 3 ft. 6-in.....80 lin. ft.	450	1 860	10 540	
SEWERS AND SEWAGE DISPOSAL.				
Sewers.				
Main sewer, 8-in., purification works to drop-manhole.....670 lin. ft	760			
Branch sewer to pumping station, 6-in., 160 lin. ft.	100			
Drop-manhole	370			
Inverted siphon, 6-in.....570 lin. ft.	560	1 790		
Sewage Disposal.				
Septic Tank	1 080			
Filters	1 030			
Drains to river	200	2 310	4 100	
Carried forward			$76 230	$48 410

TABLE 10.—(*Continued.*)

Brought forward	....	....	$76 230	$48 410
MISCELLANEOUS PIPING.				
Station Water Supply	....	$680	....	....
By-pass to filtered-water suction well, 16-in., 90 lin. ft.	....	410	....	....
Suction to flushing pump, 12-in. ... 70 lin. ft.	....	110	....	....
Water supply, 6-in., pumping station to purification works ... 350 lin. ft.	....	220	....	....
Wash-water, 10-in., pumping station to wash water tank ... 140 lin. ft.	....	170	....	....
Hydrant connections to force mains	....	220	1 810	....
TELEPHONE, ELECTRIC AND STEAM CONDUITS AND MAINS.				
Electric main, pumping station to intake gate-house	....	160	....	....
Telephone conduit, 2-duct, Dublin Pike to pumping station ... 180 lin. ft.	....	170	....	....
Telephone and electric conduit and mains, pumping station to purification works	....	1 440	....	....
Steam main, pumping station to purification works	....	380	2 150	80 190
PUMPING STATION.				
Building ... 1 273 300 cu. ft.				
Substructure ... 337 000 cu. ft.	....	44 830	....	....
Superstructure ... 936 300 cu. ft.	....	83 660	128 490	....
Chimney.				
Substructure ... 32 ft. deep	....	2 690	....	....
Superstructure ... 8 ft. diam., 160 ft. high	....	5 380	8 070	....
Machinery and Equipment.				
Pumps.				
Vertical, triple-expansion pumping engines ... 2	$160 110	....	....	....
Engine-driven centrifugal pumps ... 2	23 330	....	....	....
Flushing pump	3 500	....	....	....
Wash-water pump	2 640	....	....	....
Sump pump	300	189 880	....	....
Electric generating units and switch-board .. 2	....	10 500	....	....
Boilers and Accessories.				
Boilers ... 1 200 h.p.	16 700	....	....	....
Masonry, boiler flue	1 890	....	....	....
Boiler feed pumps ... 2	1 950	....	....	....
Surface condenser and vacuum pump	4 110	....	....	....
Open feed-water heater	1 060	25 710	....	....
Piping.				
Cold-water piping	17 030	....	....	....
Steam, feed and drain piping	9 880	26 910	....	....
Electric traveling crane	....	4 950	....	....
Miscellaneous equipment	....	1 030	258 980	395 540
Carried forward	....	....	....	$524 140

TABLE 10.—(*Continued.*)

Brought forward	....	....	....	$524 140
WATER PURIFICATION WORKS.				
Settling Basins 15 000 000 gal.				
Earthwork	....	$35 480	....	....
Roads and walks	....	1 420	....	....
Fence 1 510 lin. ft.	....	1 420	....	....
Lining.				
Puddle	$16 640	....	....	....
Concrete	20 370	....	....	....
Stone paving	3 870	40 880	....	....
Walls.				
Main dividing wall 400 lin. ft.	37 960	....	....	....
Lateral dividing walls 800 lin. ft.	26 560	....	....	....
Baffle walls 720 lin. ft.	6 630	....	....	....
Deflectors and drain chambers	830	71 980	....	....
Piping.				
Flushing main and branches	2 060	....	....	....
Coagulant piping and indicator	1 260	3 320	....	....
Gate-House.				
Superstructure 90 900 cu. ft.	13 170	....	....	....
Hand traveling cranes 2	1 100	14 270	$168 770	....
Head-House.				
Substructure 92 900 cu. ft.				
Earthwork	380	....	....	....
Concrete	10 200	....	....	....
Steel reinforcement	540	....	....	....
Piping, valves, and appurtenances	2 210	....	....	....
Head-house weirs	1 010	....	....	....
Iron and steelwork	330	14 670	....	....
Superstructure 144 000 cu. ft.	....	14 560	....	....
Equipment in Superstructure.				
Dissolving tanks 4	900	....	....	....
Slaking tanks 3	1 420	....	....	....
Solution tanks 9	2 500	....	....	....
Piping, regulators, and appurtenances	5 610	10 430	39 660	....
Air-Wash Equipment in Head and Saturator Houses.				
Air compressor	....	780	....	....
Air tanks 3	....	1 960	....	....
Air controller	....	500	....	....
Piping	....	230	3 470	....
Lime-Saturator House.				
Lime Saturators 6				
Earthwork	660	....	....	....
Concrete and brick masonry	10 360	....	....	....
Steel reinforcement	2 790	....	....	....
Piping and valves	2 850	....	....	....
Iron and steelwork	940	....	....	....
Stirring machinery	6 810	24 410	....	....
Superstructure 120 300 cu. ft.	....	8 140	32 550	....
Carried forward	....	....	$244 450	$524 140

TABLE 10.—(*Continued.*)

Brought forward	....	....	$244 450	$524 140
WATER PURIFICATION WORKS (*Continued*).				
Mixing Tanks, 2 ....1 270 000 gal.				
Earthwork	....	$4 580	....	....
Concrete and brick masonry	....	32 440	....	....
Steel reinforcement	....	2 350	....	....
Piping, valves and stop planks	....	3 850	....	....
Iron and steelwork	....	1 010	44 230	....
Storage House.				
Superstructure ....152 500 cu. ft.	....	9 740	....	....
Apron conveyor	....	3 080	....	....
Scales and trucks	....	60	12 880	....
Office and Laboratory.				
Substructure.				
Earthwork	$500	....	....	....
Concrete	2 600	....	....	....
Steel reinforcement	80	....	....	....
Iron and steelwork	140	3 320	....	....
Superstructure ....46 100 cu. ft.	....	8 220	....	....
Furniture and Equipment				
Furniture and fittings	880	....	....	....
Laboratory equipment	2 860	3 740	15 280	....
Filter Gallery.				
Substructure	....	2 250	....	....
Superstructure..................71 700 cu. ft.	....	8 410	....	....
Filters 10				
Concrete and brick masonry	21 250	....	....	....
Steel reinforcement	3 430	....	....	....
Ironwork	410	....	....	....
Strainer systems. ....10 890 sq. ft.	3 740	....	....	....
Air systems ....10 890 sq. ft.	5 500	....	....	....
Filter gravel..................300 cu. yd.	2 050	....	....	....
Filter sand..................1 010 cu. yd.	6 960	43 340	....	....
Operating tables 10	....	6 260	....	....
Filter controllers..................10	....	8 920	....	....
Piping and valves	....	29 670	....	....
Wash-water controller and by-pass	....	2 860	....	....
Gauge-board, sampling devices, and connections	....	1 000	102 710	....
Filtered-Water Reservoirs, 2.......10 000 000 gal.				
Earthwork	....	29 500	....	....
Puddle water-proofing on vaulting	....	1 480	....	....
Concrete	....	57 440	....	....
Steel reinforcement	....	3 050	....	....
Piping, valves, and indicators	....	6 700	....	....
Iron and steelwork	....	130	98 300	....
Carried forward	....	....	$517 850	$524 140

TABLE 10.—(*Continued.*)

Brought forward	....	....	$517 850	$524 140
WATER PURIFICATION WORKS—(*Continued*).				
Wash-Water Tank and Pipe, and Shelter and Tool House.				
Wash-water tank .... 104 000 gal.				
Foundations	$840	....	....	....
Piers	650	....	....	....
Tank	3 090	$4 580	....	....
Shelter and tool-house under tank . . 34 700 cu. ft.	....	6 610	....	....
Wash-water pipe, 30-in., from tank to purification works .... 250 lin. ft.	....	1 960	13 150	....
Supplies for Preliminary Operation of Works	....	....	460	....
Expenses Unclassified	....	....	1 020	532 480
Total Cost of Works, Exclusive of Connections to City, and Exclusive of Engineering	....	....	....	$1 056 620
CAST-IRON FORCE MAINS TO CITY.				
48-in. Venturi meter	....	....	4 030	....
36-in. mains .... 10 640 lin. ft.	....	....	139 370	....
36-in. connection to old West Side pumping station .... 180 lin. ft.	....	....	4 340	....
Connections to distribution system	....	....	12 640	....
20-in. and 24-in. Venturi meters	....	....	5 340	....
Blow-offs	....	....	1 120	....
Hydrant connections	....	....	210	167 050
IMPROVEMENT OF DUBLIN PIKE	....	....	....	13 950
Total Cost, Exclusive of Engineering	....	....	....	$1 237 620
ENGINEERING, 7.75 per cent.				
Pay-roll	....	....	84 340	....
Supplies	....	....	6 120	....
Expenses	....	....	5 490	95 950
TOTAL COST	....	....	....	$1 333 570

SUMMARY.

Land	$48 410
Work, exclusive of pumping station and water purification works	76 490
Pumping station	399 240
Water purification works	532 480
Total cost of works, exclusive of connections to city and exclusive of engineering	$1 056 620
Connections to city	181 000
Total cost, exclusive of engineering	$1 237 620
Engineering	95 950
TOTAL COST	$1 333 570

TABLE 11.—UNIT COST OF MAIN FEATURES OF WORK.

Work.	Capacity.	Total cost.	Unit cost.
*Pumping station building	1 273 300 cu. ft.	$128 490	10.1 cents per cu. ft.
†Main buildings, water purification works	534 600 cu. ft.	49 070	9.2 cents per cu. ft.
Settling basins	15 000 000 gal.	168 770	$11 250 per million gallons.
Lime saturators	6 750 000 gal. per 24 hours	24 410	3 620 per million gallons per 24 hours.
Mixing tanks	1 270 000 gal.	44 230	34 800 per million gallons.
Filtered-water reservoirs	10 000 000 gal.	98 300	9 830 per million gallons.
Water purification works:			
Settling basins	30 000 000 gal. per 24 hours	$168 770	$5 630 per million gallons per 24 hours.
Head-house		39 660	1 320
Air-wash equipment		3 470	120
Lime-saturator house		32 550	1 080
Mixing tanks		44 230	1 470
Storage house		12 880	430
Office and laboratory		15 280	510
Filter gallery		102 710	3 420
Filtered-water reservoirs		98 300	3 280
Wash-water tank, pipe, and shelter		13 150	440
Supplies for preliminary operation		460	20
Expenses unclassified		1 020	30
		$532 480	$17 750

*Includes superstructure and substructure of building.

†Includes superstructure of head-house, saturator house, storage house, office and laboratory, and filter gallery.

TABLE 12.—Water Purification Works.

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water. Pumped, million gal.	Volume of Water. Filtered, million gal.	Filter Data. Number used.	Filter Data. Hours in service, average.	Filter Data. Loss of head, maximum, in feet.	Filter Data. Wash-water, percentage.	Filter Data. Use of air.	Applied Chemicals. Pounds. Lime.	Applied Chemicals. Pounds. Soda ash.	Applied Chemicals. Pounds. Coagulant.	Applied Chemicals. Grains per gallon. Lime.	Applied Chemicals. Grains per gallon. Soda ash.	Applied Chemicals. Grains per gallon. Coagulant.	Color. River water.	Color. Filtered water.	Turbidity. River water.	Turbidity. Filtered water.	Free carbonic acid, river water.
1	24	35	0.00	14.9	13.2	9	21.0	2.5	1.3	+	30 063	16 440	0	14.1	7.7	0.00	35	3	4	0	3
2	22	33	0.00	14.6	14.1	9	20.3	2.7	1.9	+	28 290	15 780	0	13.6	7.6	0.00	42	2	4	0	3
3	38	35	0.01	13.6	12.7	9	16.6	3.2	1.4	+	26 782	14 760	0	13.7	7.6	0.00	27	1	5	—	3
4	42	37	0.21	14.5	14.1	10	17.7	2.6	1.6	+	27 765	15 840	0	13.4	7.6	0.00	27	2	5	0	3
5	48	38	0.17	15.4	13.9	10	18.3	2.8	1.0	+	30 780	16 988	595	14.0	7.7	0.28	37	2	7	0	5
6	38	37	0.02	15.0	14.5	10	19.1	7.0	1.4	+	31 085	13 860	819	14.5	6.5	0.38	16	1	8	0	4
7	20	33	tr.	15.5	15.2	10	20.2	7.0	1.6	+	29 845	15 300	791	13.5	6.9	0.37	18	2	6	0	8
8	22	32	0.00	14.9	15.1	10	20.0	6.9	1.6	+	29 704	16 680	714	13.9	7.8	0.34	13	0	—	0	9
9	31	31	0.02	16.4	14.7	10	20.4	6.7	2.0	+	32 101	18 360	336	13.7	7.8	0.14	9	1	4	0	5
10	34	33	0.04	12.7	12.9	9	20.5	6.5	1.0	+	26 030	15 200	0	14.3	8.4	0.00	13	0	5	0	5
11	41	34	0.22	14.7	14.5	10	20.3	7.0	0.7	+	31 510	17 200	0	15.0	8.2	0.00	10	0	5	0	8
12	18	33	0.17	15.9	15.4	10	19.7	5.8	0.9	+	30 134	15 900	0	13.3	7.0	0.00	13	0	5	0	7
13	14	32	0.30	18.5	16.0	10	23.3	3.8	0.7	+	41 552	16 980	0	15.7	6.4	0.00	15	0	5	0	6
14	31	28	tr.	17.2	15.6	10	20.2	3.9	1.9	+	38 220	14 520	0	15.5	5.9	0.00	10	0	8	0	6
15	32	26	tr.	13.9	14.4	9	20.4	4.4	0.7	+	30 576	11 460	0	15.4	5.8	0.00	7	0	13	0	4
16	29	33	0.32	15.9	14.6	10	18.9	4.4	1.2	+	34 754	19 560	0	15.3	8.6	0.00	10	0	7	0	4
17	26	31	tr.	14.6	13.0	10	19.0	2.3	1.1	+	32 544	18 540	0	15.6	8.9	0.00	13	0	5	0	6
18	25	32	tr.	14.5	15.0	10	18.1	4.0	1.1	+	32 296	17 460	0	15.6	8.4	0.00	10	0	5	0	4
19	27	32	0.00	16.0	14.4	10	20.7	3.0	2.4	+	35 266	18 660	0	15.4	8.2	0.00	10	0	5	0	4
20	32	33	0.00	14.9	14.0	10	18.6	2.6	0.6	+	32 487	17 880	0	15.2	8.4	0.00	10	0	5	0	6
21	35	32	0.00	14.9	14.6	10	19.2	8.0	3.9	+	31 825	17 820	0	14.9	8.4	0.00	13	0	6	0	4
22	45	33	0.12	14.9	14.4	10	18.8	8.0	3.9	+	31 819	18 180	0	14.9	8.5	0.00	12	0	5	0	5
23	52	35	0.28	14.9	14.5	10	18.8	8.0	4.5	+	31 161	17 940	0	14.6	8.4	0.00	13	0	8	0	4
24	57	41	0.00	12.9	12.4	10	16.6	8.0	6.0	+	27 274	16 320	0	14.8	8.8	0.00	20	0	8	0	5
25	45	43	0.00	14.8	14.6	9	20.6	8.0	4.7	+	31 632	18 660	0	14.9	8.8	0.00	13	0	18	0	4
26	37	40	0.00	14.6	14.0	9	20.3	8.0	4.3	+	30 709	17 880	0	14.7	8.6	0.00	15	0	10	0	5
27	37	38	0.00	14.1	13.8	9	19.7	8.0	6.0	+	30 527	17 160	0	15.1	8.5	0.00	15	0	10	0	4
28	30	36	0.04	14.2	13.5	9	19.6	8.0	3.8	+	28 350	15 000	0	14.0	7.4	0.00	15	0	10	0	4
29	34	36	0.39	14.3	14.0	9	19.0	8.0	4.3	+	23 950	14 840	0	14.7	7.3	0.00	20	0	10	0	3
30	22	33	0.21	15.8	15.0	9	20.8	8.0	4.1	+	32 850	19 260	0	14.5	8.5	0.00	15	0	12	0	3
31	14	32	tr.	16.1	14.5	9	21.9	7.9	4.3	+	34 200	20 220	0	14.9	8.8	0.00	15	0	12	0	4
Av.	32	34	....	15.0	14.3	10	19.6	5.7	2.4	....	31 164	16 795	105	14.6	7.8	0.05	16	0.4	7	0	5

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for January, 1909.

Analytical Results, in Parts per Million.																			Bacteriological Tests.						
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.				
																					River water.		Filtered water.		
																					1 c. c.		1 c. c.		50 c. c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
417	135	132	110	232	73	63	50	0	1	7	43	185	62	69	59	45	16	75	3	0	0	0	0	0	0
429	120	126	120	237	51	59	52	3	1	8	44	192	69	67	67	42	14	75	3	1	0	0	0	0	0
423	149	132	120	237	71	59	50	0	1	9	41	186	78	73	70	37	10	75	1	2	+	0	0	0	0
425	143	140	124	235	69	65	53	0	0	5	48	190	74	75	71	43	12	50	3	1	0	0	0	0	0
399	116	127	119	221	57	62	53	7	2	3	50	178	59	65	66	38	13	60	5	1	0	0	0	0	0
394	120	111	106	221	42	41	49	6	0	5	44	173	78	68	57	40	11	150	4	3	0	0	0	0	0
406	124	119	101	227	55	36	32	0	0	2	30	178	69	83	69	34	19	175	4	2	0	0	0	0	0
417	142	120	104	237	71	41	29	0	0	5	24	180	71	78	75	43	8	250	5	2	0	0	0	0	0
430	147	141	113	242	71	63	39	0	0	1	38	188	76	78	74	41	10	275	4	3	0	0	0	0	0
425	141	148	130	239	66	71	50	0	0	0	48	186	76	76	80	45	18	450	5	0	0	0	0	0	0
408	129	130	128	228	55	61	54	9	1	5	49	180	74	69	74	39	20	600	2	3	0	0	0	0	0
406	122	116	107	229	60	55	48	6	5	7	41	177	62	61	59	44	17	150	1	0	0	0	0	0	0
416	129	114	106	235	50	54	48	18	10	18	30	181	79	60	57	42	12	225	2	0	0	0	0	0	0
419	131	125	121	238	55	48	44	1	12	25	19	181	76	77	77	45	10	175	1	0	0	0	0	0	0
416	132	159	122	236	46	41	39	2	9	20	19	180	86	118	83	50	9	—	1	0	0	0	0	0	0
414	121	141	123	235	46	44	37	10	10	16	21	179	74	97	86	43	11	25	2	2	0	0	0	0	0
406	99	106	110	232	48	49	41	18	11	20	21	174	50	57	69	43	11	135	2	0	0	0	0	0	0
414	110	105	100	237	51	52	47	15	16	21	26	177	59	54	53	43	10	200	3	0	0	0	0	0	0
428	121	109	97	242	46	50	47	16	14	26	21	186	75	59	49	44	10	220	0	1	0	0	0	0	0
431	120	122	105	244	58	55	46	22	13	22	24	187	62	67	59	43	10	160	0	0	+	0	0	0	0
425	100	136	116	241	62	69	45	36	0	9	36	184	38	67	71	45	11	120	10	2	0	0	0	0	0
401	100	121	108	225	66	59	39	38	15	7	32	176	34	61	69	43	11	50	7	7	0	0	0	0	0
394	93	120	94	219	64	60	39	34	2	12	27	175	29	60	55	42	11	150	40	6	0	0	0	0	0
395	116	117	89	219	92	66	35	64	10	14	21	176	23	51	54	37	6	3 900	44	10	+	0	0	0	0
411	96	116	91	227	65	69	47	41	19	27	20	184	31	47	44	37	7	2 500	30	30	0	+	0	0	0
434	113	117	93	238	51	62	44	27	2	20	21	196	62	55	49	45	11	400	40	6	0	0	0	0	0
424	110	126	96	236	65	59	34	33	0	8	26	189	45	68	62	45	9	550	60	10	0	0	0	0	0
426	115	122	93	237	56	56	31	26	4	6	25	189	59	66	62	45	12	425	—	4	0	0	0	0	0
425	123	117	111	235	58	47	30	16	0	8	22	190	64	71	80	45	13	425	—	4	0	0	0	0	0
441	130	141	107	241	66	61	32	36	0	3	29	200	64	79	75	46	10	500	45	12	0	0	0	0	0
437	114	129	105	238	62	64	36	20	2	5	31	199	52	65	69	44	16	500	12	4	0	0	0	0	0
417	121	125	109	233	60	56	43	16	5	11	31	184	61	69	66	42	12	435	11	3	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water.		Filter Data.					Applied Chemicals.						Color.		Turbidity.		Free carbonic acid, river water.
				Pumped, million gal.	Filtered, million gal.	Number used.	Hours in service, average.	Loss of head, maximum, in feet.	Wash-water, percentage.	Use of air.	Pounds.			Grains per gallon.			River water.	Filtered water.	River water.	Filtered water.	
											Lime.	Soda ash.	Coagulant.	Lime.	Soda ash.	Coagulant.					
1	28	32	0.00	16.4	15.6	10	20.5	8.0	3.0	0	35 000	21 480	0	14.9	9.2	0	12	0	12	0	3
2	22	32	0.00	15.7	15.5	10	20.0	8.0	3.4	0	35 950	22 260	0	16.0	9.9	0	32	0	15	0	5
3	28	32	0.00	15.3	14.4	10	18.1	8.0	4.9	0	34 800	22 638	0	15.9	10.3	0	40	0	15	0	5
4	41	34	0.00	14.6	14.3	10	18.3	8.0	5.5	0	30 265	21 384	0	15.1	10.2	0	45	0	15	0	4
5	47	35	0.31	14.6	14.2	10	16.9	8.0	5.8	0	24 315	19 038	0	11.6	9.1	0	50	0	15	0	6
6	41	39	0.08	14.7	13.9	10	17.8	8.0	6.1	0	22 608	16 020	0	10.7	7.6	0	50	0	20	0	5
7	34	38	0.00	12.9	12.3	10	16.0	8.0	4.3	0	18 848	14 940	0	10.2	8.1	0	55	2	15	0	3
8	33	36	0.00	14.2	14.0	10	17.4	8.0	5.0	0	21 440	16 380	0	10.6	8.1	0	—	0	—	0	3
9	39	38	0.40	16.7	13.7	10	20.1	8.0	4.2	0	26 336	19 380	0	11.0	8.1	0	18	0	20	0	3
10	28	38	tr.	14.8	14.1	10	17.9	7.6	6.1	0	25 888	19 820	0	12.2	9.4	0	18	1	22	0	3
11	26	34	0.00	14.9	14.2	10	19.3	8.0	1.2	0	27 840	21 780	0	13.1	10.2	0	19	0	20	0	4
12	32	37	0.54	15.8	13.9	10	17.8	8.0	6.1	0	30 561	23 520	0	13.5	10.4	0	17	3	20	0	4
13	44	39	0.01	14.6	13.5	10	16.9	7.5	3.3	0	29 899	21 660	0	14.3	10.4	0	17	0	22	0	5
14	45	39	0.56	13.2	12.3	10	15.4	7.9	5.2	0	24 056	21 680	72	12.8	11.5	0.1	30	0	48	0	4
15	33	37	0.42	12.6	15.3	10	15.0	10.0	14.2	0	15 744	21 190	1 242	8.7	11.8	0.7	40	1	86	0	4
16	26	37	0.24	16.1	14.5	10	20.1	8.0	5.8	0	11 100	13 650	2 311	4.8	5.9	1.0	65	3	255	1	2
17	22	25	0.00	14.4	14.2	10	21.5	6.7	3.3	0	3 620	8 880	3 177	1.8	4.3	1.6	70	8	431	3	3
18	33	35	0.00	14.5	14.4	10	22.0	6.6	8.2	0	14 680	7 150	11 640	7.1	3.4	5.6	60	30	332	4	3
19	39	35	0.21	15.8	13.3	10	19.0	6.8	4.4	0	16 060	7 230	10 122	7.1	3.2	4.5	100	20	184	2	3
20	38	35	0.00	13.6	13.7	10	15.6	7.0	5.6	0	11 640	7 785	7 638	6.0	4.0	3.9	90	13	184	0	3
21	37	36	tr.	12.5	11.5	10	14.5	3.5	3.5	0	10 780	5 190	5 700	6.0	2.9	3.2	75	10	252	0	3
22	38	37	0.00	13.6	13.5	10	16.7	4.7	5.6	0	9 520	7 205	5 280	4.9	3.7	2.2	75	10	214	0	3
23	50	40	2.05	13.8	13.4	10	16.6	6.9	4.8	0	7 800	6 825	8 155	3.9	3.5	4.1	75	8	482	0	3
24	48	48	0.14	14.5	13.5	10	22.5	3.0	6.0	0	9 330	5 285	8 978	4.5	2.5	4.3	100	13	1 311	0	2
25	25	45	tr.	14.1	13.1	10	23.5	3.8	1.5	0	10 520	1 890	13 269	5.2	2.4	6.6	—	17	1 220	5	3
26	33	40	0.00	16.2	16.3	10	21.3	7.0	7.1	0	14 900	0	13 137	6.4	0	5.7	70	25	867	0	3
27	37	38	tr.	17.8	17.1	10	20.4	6.7	9.0	0	14 155	3 160	9 523	5.6	1.8	3.7	100	—	545	0	2
28	32	38	0.01	16.9	14.4	10	18.6	6.5	8.0	0	7 567	4 120	10 500	3.1	1.7	4.3	80	15	302	0	2
Av.	35	37	....	14.8	14.1	10	18.6	7.1	5.4	..	19 472	13 626	3 955	9.1	6.6	1.8	54	7	256	0.5	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for February, 1909.

Analytical Results, in Parts per Million.																		Bacteriological Tests.							
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.				
																					River water.		Filtered water.		
																					1 c. c.		1 c. c.		50 c.c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
450	119	140	107	245	62	69	37	26	0	6	31	205	57	71	70	45	13	400	9	2	0	0	0	0	0
447	111	142	102	243	62	70	33	30	0	3	30	204	49	72	69	48	11	375	7	2	0	0	0	0	0
427	108	136	96	232	88	77	37	62	9	10	27	195	20	59	59	46	11	200	3	2	0	0	0	0	0
416	121	135	92	223	97	85	47	63	21	22	25	193	24	50	46	40	7	400	5	1	0	0	0	0	0
405	122	137	96	220	90	86	52	20	12	27	25	185	32	51	44	42	15	300	4	2	0	0	0	0	0
405	120	140	108	220	63	81	54	13	0	9	45	185	57	59	54	32	4	725	15	2	0	0	0	0	0
416	142	143	107	223	83	79	48	11	0	2	46	193	59	64	59	34	13	—	—	—	0	0	0	0	0
419	145	163	132	225	90	84	58	2	0	0	46	194	55	79	74	43	23	450	5	5	0	0	0	0	+
419	142	168	142	224	78	91	67	4	0	0	50	195	65	77	75	40	21	725	20	13	0	0	0	0	0
405	104	164	133	219	69	83	61	17	0	0	44	186	35	81	72	40	23	2 000	120	22	+	0	0	0	+
421	110	138	116	223	64	74	52	16	4	1	51	198	47	64	64	38	15	600	—	10	+	0	0	0	0
419	103	136	102	218	79	78	51	35	0	5	46	201	24	58	51	38	10	400	15	8	0	0	0	0	—
409	115	122	99	209	72	74	47	62	0	4	43	200	43	48	52	40	17	1 200	10	6	0	0	0	0	0
389	113	123	94	180	95	66	47	67	12	15	32	209	18	57	47	38	8	17 500	400	15	+	+	0	0	0
356	110	118	100	150	84	79	51	24	31	26	25	206	25	39	49	25	6	16 000	50	6	+	+	0	0	0
220	128	110	87	92	84	65	55	32	9	27	28	128	44	45	32	15	4	50 000	250	80	+	+	0	0	0
167	154	104	77	75	124	63	40	0	0	7	33	92	30	41	37	14	6	100 000	50 000	500	+	+	0	0	0
195	173	128	103	83	120	74	58	44	0	0	26	112	53	54	45	13	5	60 000	1 000	800	+	+	+	0	+
206	182	132	116	85	103	43	48	67	0	0	10	121	79	88	68	18	—	80 000	100	150	+	+	0	0	0
186	158	144	123	81	84	44	42	22	0	0	18	105	74	100	81	23	8	80 000	110	22	+	+	0	0	0
147	167	125	127	68	124	44	40	38	0	0	16	79	42	81	87	17	8	75 000	80	7	+	+	0	0	0
142	152	134	110	66	130	85	45	32	0	0	28	76	22	49	65	10	8	75 000	95	8	+	+	0	0	0
140	142	114	96	69	114	84	56	2	0	1	55	71	28	30	40	9	8	73 000	350	25	+	+	0	0	0
94	142	106	97	56	136	66	52	28	0	0	30	38	6	40	45	9	6	100 000	450	100	0	+	0	0	+
72	147	97	89	54	127	74	62	33	0	0	18	18	20	23	27	10	7	55 000	1 200	285	+	+	0	0	+
85	179	98	88	56	143	54	54	54	0	0	20	29	37	44	33	6	2	14 000	145	40	0	0	0	0	0
93	186	151	101	59	150	101	60	54	17	22	38	34	36	49	41	9	3	53 000	250	32	+	+	0	0	0
117	149	126	105	68	120	87	62	8	17	37	25	49	29	39	43	15	4	30 000	1 100	70	+	+	0	0	0
288	137	131	105	149	98	74	51	31	5	8	32	139	40	58	55	27	10	32 825	2 146	82	...	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water.		Filter Data.					Applied Chemicals.											
											Pounds.			Grains per gallon.			Color.		Turbidity.			
				Pumped, million gal.	Filtered, million gal.	Number used.	Hours in service, average.	Loss of head, maximum, in feet.	Wash-water, percentage.	Use of air.	Lime.	Soda ash.	Coagulant.	Lime.	Soda ash.	Coagulant.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Free carbonic acid, river water.
1	37	42	0.35	15.2	15.6	10	18.7	6.3	5.6	0	5 888	3 372	10 614	2.7	1.6	4.9	80	20	188	25	0	3
2	45	41	0.14	16.2	14.8	10	17.7	6.0	5.1	0	9 419	8 595	8 936	4.1	3.7	3.9	75	30	135	25	0	2
3	40	40	0.22	16.0	14.7	10	19.1	4.8	6.8	0	12 440	14 873	6 345	5.4	6.5	2.8	75	30	100	20	0	3
4	29	41	0.00	14.8	14.8	10	16.9	4.0	5.9	0	10 912	15 430	5 022	5.2	7.3	2.4	65	35	90	20	1	3
5	30	40	0.00	16.4	14.5	10	18.1	4.9	4.5	0	17 916	17 025	3 810	7.6	7.3	1.6	65	25	93	20	0	3
6	40	42	0.01	16.6	13.8	10	15.8	6.0	6.0	0	19 425	17 250	3 454	8.2	7.3	1.5	65	20	92	20	0	4
7	41	42	0.00	12.9	11.4	10	14.5	3.7	5.3	0	14 275	12 525	2 716	7.7	6.8	1.5	50	12	71	20	0	4
8	39	40	0.03	15.2	13.2	10	15.9	5.0	4.5	0	15 750	16 275	2 603	7.2	7.5	1.2	45	0	52	20	0	3
9	49	42	0.98	15.5	12.7	10	16.9	3.3	5.2	0	14 975	15 900	1 660	6.8	7.2	0.7	60	0	73	20	0	2
10	43	46	tr.	13.4	12.6	10	17.8	4.7	5.0	0	9 530	9 062	7 952	5.0	4.7	4.0	—	—	210	20	0	2
11	39	44	0.00	14.3	12.9	10	20.5	4.0	6.9	0	8 560	5 228	11 178	4.2	2.6	5.5	—	5	479	20	0	3
12	36	43	tr.	13.7	12.8	10	20.5	3.2	6.6	0	7 664	4 235	8 148	3.9	2.2	4.2	—	10	373	20	0	2
13	42	43	0.00	12.4	13.1	10	21.6	2.8	7.2	0	9 296	4 970	6 592	5.2	2.8	3.7	—	10	352	30	3	4
14	35	42	tr.	13.8	11.2	10	20.8	3.0	8.1	0	10 960	7 865	7 763	5.6	4.0	4.0	—	30	197	30	3	3
15	34	41	0.00	14.3	13.0	10	17.9	3.4	6.7	0	11 712	7 595	6 884	5.7	3.7	3.4	70	12	120	20	3	5
16	32	41	0.03	13.6	12.7	10	16.9	2.7	6.1	0	13 680	10 545	4 894	7.0	5.4	2.5	—	18	91	0	3	5
17	29	39	0.00	13.7	13.0	10	18.0	3.6	6.8	0	14 037	13 325	2 864	7.2	6.8	1.5	55	15	72	0	0	3
18	33	41	0.01	13.4	12.7	10	14.3	9.7	6.9	0	13 446	12 950	1 850	7.0	6.7	1.0	52	3	56	5	0	4
19	46	43	0.07	13.9	12.7	10	15.9	4.0	4.6	0	14 202	12 040	1 875	7.1	6.1	0.9	—	2	47	10	0	4
20	40	42	0.00	14.2	13.4	10	16.5	3.6	3.8	0	13 824	14 700	1 995	6.8	7.2	1.0	—	0	37	15	0	4
21	36	41	0.00	11.5	10.8	10	17.6	3.7	5.3	0	11 799	11 895	1 605	7.2	7.2	1.0	70	0	35	15	0	4
22	34	40	0.00	14.2	13.1	10	19.0	2.8	6.8	0	16 513	16 725	1 785	8.1	8.2	0.9	55	5	26	15	0	3
23	45	45	0.00	13.9	12.4	10	17.7	2.8	3.9	0	15 912	17 360	1 659	8.0	8.7	0.8	70	0	25	15	0	4
24	44	43	0.65	12.7	12.3	10	16.5	3.3	3.8	0	14 752	15 680	1 004	8.1	8.6	0.6	70	0	25	15	0	4
25	36	41	0.18	13.1	12.3	10	17.2	2.9	4.7	0	14 554	14 700	1 237	7.7	7.8	0.7	70	0	25	15	0	3
26	34	42	0.00	13.5	12.3	9	19.4	2.6	2.7	0	14 950	13 650	1 312	7.7	7.1	0.7	30	0	27	15	0	5
27	44	44	0.00	13.3	12.5	9	19.7	5.9	3.6	0	14 924	14 560	1 253	7.7	7.7	0.7	30	3	30	15	0	5
28	48	46	0.00	11.8	10.8	10	18.4	4.1	3.3	0	11 544	13 020	1 043	6.8	7.7	0.6	35	0	47	15	0	3
29	39	43	tr.	14.3	12.9	10	19.5	3.7	3.1	0	13 858	14 397	1 320	6.8	7.0	0.6	35	0	68	15	0	3
30	39	42	0.01	13.4	12.1	10	18.0	3.6	2.5	0	11 778	11 574	1 515	6.1	6.0	0.8	35	0	80	15	0	4
31	39	43	0.00	13.5	12.1	10	16.8	4.3	3.2	0	10 020	8 649	2 670	5.2	4.5	1.4	35	0	78	15	0	3
Av.	39	42	....	14.0	12.9	10	17.9	4.1	5.2	..	12 855	12 128	3 985	6.4	6.1	2.0	56	9	109	17	0.4	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for March, 1909.

Total hardness: River water.	Total hardness: Inlet to sett. basin.	Total hardness: Settled water.	Total hardness: Filtered water.	Total alkalinity: River water.	Total alkalinity: Inlet to sett. basin.	Total alkalinity: Settled water.	Total alkalinity: Filtered water.	Caustic alk.: Inlet to sett. basin.	Caustic alk.: Settled water.	Caustic alk.: Filtered water.	Mono. carb. alk., filtered water.	Incrustants: River water.	Incrustants: Inlet to sett. basin.	Incrustants: Settled water.	Incrustants: Filtered water.	Magnesium: River water.	Magnesium: Filtered water.	Bacteria per c.c.: River water.	Bacteria per c.c.: Settled water.	Bacteria per c.c.: Filtered water.	Presumptive Coli tests: River water, 1 c.c.: Smith method.	River water, 1 c.c.: Bile method.	Filtered water, 1 c.c.: Smith method.	Filtered water, 1 c.c.: Bile method.	Filtered water, 50 c.c.: Smith method.
155	172	131	85	79	116	71	41	0	0	9	32	76	55	60	44	12	2	32 500	17 000	275	+	+	0	0	+
187	175	155	119	86	137	88	49	0	0	0	24	101	37	67	71	12	6	28 000	1 000	385	+	0	+	0	+
215	153	135	124	96	122	75	65	14	0	0	26	118	32	60	59	11	6	18 000	300	330	—	+	0	0	+
231	131	105	99	103	107	65	58	11	0	0	40	128	24	41	41	15	8	8 000	25	38	0	0	0	0	0
247	124	112	96	108	99	69	56	25	0	0	48	139	25	43	40	17	9	36 000	400	300	0	0	0	0	0
246	124	80	80	114	99	52	49	41	6	0	30	131	25	28	31	17	12	45 000	170	34	0	0	0	0	0
248	121	84	71	115	96	60	53	36	20	12	41	133	25	24	18	18	6	8 000	—	1	0	—	0	—	0
259	131	84	69	119	102	51	49	36	11	22	27	141	29	33	20	19	5	9 350	12	2	0	0	0	0	0
259	134	77	61	123	106	51	41	16	3	16	25	136	27	26	20	19	4	22 000	30	0	0	0	0	0	0
185	133	91	64	94	104	60	42	30	0	10	32	91	29	31	22	15	7	60 000	70	2	0	+	0	0	0
144	131	112	76	76	111	69	41	13	0	2	39	68	20	43	35	10	6	70 000	600	2	+	+	0	0	+
144	158	128	96	81	126	76	50	0	0	0	42	63	32	52	46	9	10	125 000	2 500	300	+	+	0	0	0
139	143	114	97	83	126	72	52	8	0	0	16	56	17	42	45	12	10	30 000	700	300	+	+	0	0	+
170	146	107	98	93	124	74	55	24	0	0	18	77	22	33	43	11	8	26 000	200	300	+	+	0	0	+
196	138	97	97	101	106	60	48	24	0	0	22	95	32	37	49	13	10	7 500	95	155	0	+	0	0	0
221	136	110	96	109	101	57	52	27	0	0	26	112	35	53	44	15	10	3 750	10	9	0	+	0	0	0
228	129	109	102	115	98	55	43	43	0	0	26	113	30	54	59	17	9	2 000	0	0	+	+	0	0	0
244	107	67	84	123	96	48	46	22	4	0	36	121	11	19	38	17	8	900	—	0	0	+	0	0	0
274	109	85	68	137	86	54	46	16	4	2	44	137	23	31	22	22	8	1 000	4	0	+	0	0	0	0
276	117	88	64	136	95	49	41	17	3	3	38	140	22	39	24	21	7	550	2	0	0	0	0	0	0
290	120	92	75	142	88	54	39	16	0	3	36	148	32	38	36	21	8	700	2	1	0	0	0	0	0
304	111	86	63	149	94	59	42	14	0	3	39	155	17	27	22	21	8	400	1	1	0	0	0	0	0
311	110	82	68	157	92	55	43	12	0	5	38	155	18	27	25	24	7	150	0	0	0	0	0	0	0
324	112	88	67	163	86	62	44	16	6	6	38	161	26	26	23	22	8	140	3	1	+	0	0	0	0
319	119	94	67	163	82	69	51	0	0	5	46	156	37	25	16	22	6	750	0	2	0	+	0	0	0
323	132	97	71	162	72	61	52	4	0	4	48	161	60	35	19	20	9	700	6	0	0	+	0	0	0
322	114	106	82	159	70	52	46	12	0	3	43	163	44	54	36	24	10	4 000	2	0	+	0	0	0	0
270	101	110	91	147	85	53	42	11	0	0	40	123	16	57	49	25	8	—	—	—	+	0	0	0	0
268	107	84	84	130	80	61	42	16	0	4	38	138	27	23	42	19	7	1 250	45	0	0	0	0	0	0
247	105	84	71	118	76	58	50	16	4	5	45	129	29	25	21	19	10	2 500	15	0	+	+	0	0	0
224	113	82	66	115	72	49	45	4	0	5	40	109	41	33	21	19	10	2 700	12	1	+	0	0	0	0
241	128	99	82	119	99	61	47	17	2	4	35	122	29	38	35	17	8	18 228	828	81	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water.		Filter Data.					Applied Chemicals.											
											Pounds.			Grains per gallon.			Color.		Turbidity.			
				Pumped, million gal.	Filtered, million gal.	Number used.	Hours in service, average.	Loss of head, maximum, in feet.	Wash-water, percentage.	Use of air.	Lime.	Soda ash.	Coagulant.	Lime.	Soda ash.	Coagulant.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Free carbonic acid, river water.
1	41	44	0.00	13.8	12.5	10	17.1	5.8	6.1	0	11 140	8 485	3 383	5.6	4.3	1.7	37	0	65	25	0	3
2	48	47	0.06	13.7	12.3	10	18.4	4.7	4.7	0	12 000	9 540	2 595	6.1	4.9	1.3	30	8	52	25	0	2
3	42	43	0.01	13.1	12.6	10	17.4	5.0	3.4	0	12 380	9 225	2 074	6.6	4.9	1.1	33	—	44	25	0	2
4	43	47	0.00	12.5	10.8	10	16.6	4.6	4.0	0	11 300	9 000	1 241	6.3	5.0	0.7	33	10	42	25	0	3
5	58	49	0.00	12.5	12.4	10	17.4	4.8	2.8	0	11 380	10 350	1 013	6.4	5.8	0.6	31	2	36	25	0	2
6	60	46	1.00	13.0	12.2	10	17.2	4.3	4.0	0	10 880	9 990	2 922	5.9	5.4	1.6	43	2	148	25	0	3
7	56	51	0.00	12.8	12.0	9	19.2	5.9	2.6	0	10 330	7 971	8 144	5.6	5.4	4.4	70	10	433	25	0	3
8	46	52	tr.	13.5	12.8	10	16.5	7.8	11.7	0	8 006	2 944	13 874	4.1	1.5	7.2	80	7	487	72	0	3
9	34	49	0.04	14.2	12.6	10	18.2	6.2	10.1	0	10 102	3 808	14 402	5.0	1.9	7.1	77	11	314	45	0	3
10	31	44	tr.	12.5	12.2	10	16.9	7.8	4.1	0	6 354	4 176	8 945	3.6	2.3	5.0	77	12	278	30	0	3
11	39	44	0.00	11.8	11.1	10	15.5	8.1	10.1	0	8 280	5 848	9 460	4.9	3.5	5.6	70	14	178	34	0	3
12	53	47	0.00	13.2	12.4	10	17.4	8.0	2.6	0	9 634	9 984	10 404	5.1	5.3	5.5	67	22	116	25	0	3
13	53	47	0.16	11.3	11.8	10	19.6	8.0	2.0	0	8 470	9 420	5 954	5.2	5.8	3.7	60	19	96	20	0	3
14	42	45	0.00	11.3	11.6	9	17.0	7.2	0.9	0	8 064	9 630	5 286	5.0	6.0	3.3	55	23	74	20	0	3
15	45	47	0.00	14.3	11.8	10	15.8	7.9	3.4	0	13 802	14 590	5 864	6.7	7.1	2.9	50	22	54	20	0	3
16	56	50	0.00	13.4	12.0	8	20.8	4.2	0.7	0	13 614	15 280	4 691	7.1	8.0	2.4	35	16	50	20	0	3
17	64	52	tr.	14.0	12.7	9	18.0	7.2	1.4	0	16 770	13 760	3 879	8.4	6.9	1.9	37	12	42	15	0	3
18	66	51	0.00	11.2	10.5	10	15.0	8.0	1.9	0	11 232	11 681	1 655	7.0	7.3	1.0	29	11	29	10	0	3
19	59	56	0.03	13.7	12.1	10	17.8	8.1	3.2	0	15 184	15 229	1 453	7.8	7.8	0.7	33	4	30	10	0	3
20	44	49	0.25	12.5	11.7	10	15.0	8.0	2.0	0	12 532	11 650	1 012	7.0	6.5	0.6	31	3	29	10	0	3
21	55	56	0.48	12.4	11.5	10	16.2	8.1	1.6	0	14 638	13 800	1 147	8.3	7.8	0.6	31	2	31	10	0	2
22	52	54	0.00	14.2	11.5	10	16.7	8.0	1.7	0	14 534	14 450	2 655	7.2	7.1	1.3	31	2	35	10	0	2
23	49	57	0.00	12.1	11.9	10	17.9	8.1	3.2	0	14 014	11 900	1 057	8.1	6.9	0.6	28	1	30	10	0	3
24	46	54	0.00	12.2	12.0	10	19.3	4.4	3.5	0	12 636	12 550	975	7.2	7.2	0.6	31	1	30	10	0	2
25	60	57	0.34	11.4	10.4	10	18.6	3.8	3.4	0	14 040	10 950	1 028	8.6	6.7	0.6	29	2	35	10	0	3
26	47	54	0.00	11.7	12.4	10	21.2	3.1	2.6	0	12 922	12 000	2 415	7.7	7.2	1.4	32	1	56	10	0	3
27	54	55	0.05	12.5	11.8	10	21.1	5.5	3.2	0	17 046	11 950	2 670	9.5	6.7	1.5	36	1	52	10	0	3
28	45	53	tr.	12.2	11.7	10	20.0	7.8	3.9	0	10 798	9 350	2 610	6.2	5.4	1.5	36	1	50	10	0	3
29	60	55	tr.	12.4	12.0	10	21.1	7.0	2.8	0	14 388	8 750	3 630	8.1	4.9	2.0	36	2	48	10	0	3
30	62	60	0.78	13.2	12.0	10	20.1	4.2	3.5	0	12 078	10 447	5 147	6.4	5.5	2.7	35	1	96	25	0	2
Av.	50	50	....	12.7	11.9	10	18.0	6.4	3.7	..	11 951	10 290	4 386	6.5	5.7	2.4	43	8	102	21	0	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for April, 1909.

Analytical Results, in Parts per Million.																		Bacteriological Tests.								
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.					
																					River water.		Filtered water.			
																					1 c. c.		1 c. c.		50 c.c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
224	123	102	74	117	74	54	37	10	0	3	34	107	49	48	37	18	10	2 700	250	4	0	0	0	0	0
247	123	101	99	122	69	49	44	7	0	0	26	125	53	52	55	19	13	1 500	250	95	0	+	0	0	0
252	116	106	90	125	72	50	38	12	0	0	30	127	44	56	52	19	11	1 500	90	60	+	0	0	0	0
259	120	96	96	128	68	45	40	12	1	0	28	131	52	51	56	17	8	725	130	1	0	0	0	0	0
260	108	100	87	130	72	46	36	2	2	0	32	130	36	53	52	21	7	700	20	2	0	0	0	0	0
271	113	97	91	137	66	49	39	8	0	0	38	134	47	48	52	22	9	13 500	50	10	+	+	0	0	0
181	122	107	87	94	78	54	41	16	0	0	38	87	44	53	46	18	11	68 000	1 000	45	+	+	0	0	0
138	133	106	115	81	89	53	48	11	0	0	22	58	43	53	67	17	15	38 000	3 000	80	0	0	0	0	0
147	124	93	121	87	96	41	46	16	0	0	8	60	28	52	76	18	12	40 000	1 700	295	0	+	0	0	0
148	127	113	125	87	99	40	45	0	0	0	2	61	28	73	80	14	8	25 000	2 000	290	+	0	0	+	0
158	118	126	120	95	102	59	46	12	0	0	2	63	16	67	74	16	7	10 000	80	300	+	0	0	0	0
189	118	103	109	101	78	51	47	26	0	0	0	88	40	53	62	21	10	12 000	200	210	+	0	0	0	0
211	104	100	100	109	91	54	47	9	0	0	6	102	13	46	52	18	13	8 000	2 000	150	+	+	0	0	+
221	119	95	90	116	75	68	57	17	0	0	14	105	44	27	32	16	10	2 500	155	110	+	0	0	0	0
244	131	104	91	129	60	70	60	30	0	0	20	116	71	34	31	18	9	1 000	86	20	+	0	0	0	+
247	98	84	94	135	90	66	64	22	0	0	30	112	8	18	30	19	11	500	16	15	0	0	0	0	0
262	93	77	77	140	82	65	63	26	0	0	36	122	11	12	14	21	13	1 500	190	160	0	0	0	0	0
290	116	77	65	155	66	53	55	28	0	0	38	135	50	24	10	20	9	1 500	110	90	0	0	0	0	0
278	115	83	67	149	73	60	46	33	0	0	34	129	42	23	21	19	7	1 000	500	200	0	0	0	0	0
293	110	69	63	158	78	58	55	0	0	0	40	134	32	11	7	19	7	1 500	325	310	0	0	0	0	0
293	103	92	70	154	77	55	48	17	0	0	40	139	26	37	22	21	8	7 500	1 750	350	+	+	0	0	0
287	104	80	72	154	85	52	48	3	0	0	40	133	19	28	24	21	10	300	2 000	600	+	+	0	0	0
289	118	91	73	156	84	51	43	0	0	0	38	133	34	40	30	23	10	1 250	5 000	70	0	0	0	0	0
297	106	83	66	162	82	56	42	0	0	0	34	135	24	27	24	23	10	1 750	1 250	1 100	+	+	0	0	0
291	109	86	67	164	73	58	45	9	0	0	38	127	36	28	21	22	10	1 500	1 600	900	+	0	0	0	0
276	109	87	75	157	88	52	48	0	0	0	42	119	21	35	28	22	11	2 000	1 000	1 250	+	+	0	0	+
262	90	66	66	148	81	48	40	39	0	0	32	114	9	18	26	22	9	1 150	130	50	+	0	0	0	0
259	102	68	57	150	75	52	40	11	6	0	32	109	28	16	17	19	7	1 850	175	450	0	0	0	0	0
248	99	83	52	144	75	52	36	13	0	0	30	104	24	31	16	19	5	1 900	280	225	0	0	0	0	0
248	103	78	66	142	61	42	40	13	0	0	28	106	42	35	26	18	8	4 700	650	480	0	0	0	0	0
242	112	92	84	131	79	53	46	13	0.3	0.1	28	111	34	38	38	19	10	8 500	8 662	264	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water.		Filter Data.					Applied Chemicals.											
											Pounds.			Grains per gallon.			Color.		Turbidity.			
				Pumped, million gal.	Filtered, million gal.	Number used.	Hours in service, average.	Loss of head, maximum, in feet.	Wash-water, percentage.	Use of air.	Lime.	Soda ash.	Coagulant.	Lime.	Soda ash.	Coagulant.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Free carbonic acid, river water.
1	46	57	tr.	12.5	11.8	10	20.9	7.0	2.3	0	8 754	4 878	12 648	4.9	2.7	7.1	67	3	1 017	30	0	3
2	45	53	tr.	11.1	10.3	10	17.3	9.3	3.8	0	5 680	4 225	13 150	3.6	2.7	8.3	65	2	1 081	30	0	4
3	47	51	0.36	11.8	12.0	10	20.0	8.1	6.9	0	7 040	3 900	11 556	4.2	2.3	6.8	70	2	485	35	0	3
4	45	49	0.50	13.0	13.0	10	20.2	8.1	10.8	0	8 895	4 140	15 464	4.8	2.2	8.3	70	4	297	104	0	4
5	57	50	0.17	13.0	12.5	10	21.0	8.1	7.3	0	8 739	8 645	8 990	4.7	4.6	4.8	60	6	199	67	0	4
6	66	52	0.00	13.0	12.3	10	21.6	8.0	6.4	0	12 296	8 735	5 870	6.6	4.7	3.2	47	18	140	38	0	3
7	59	56	0.01	14.1	12.0	10	22.2	8.0	4.9	0	14 850	9 140	4 840	7.4	4.5	2.4	55	18	114	25	0	3
8	67	59	0.00	12.6	12.4	10	19.1	8.0	2.5	0	12 055	7 300	3 985	6.7	4.1	2.2	39	13	97	25	0	3
9	66	63	0.52	12.0	10.5	10	18.1	8.0	4.9	0	14 525	7 420	6 007	8.5	4.3	3.5	37	5	83	25	0	3
10	51	61	0.94	12.4	11.9	10	20.5	8.1	4.2	0	14 070	5 500	11 908	7.9	3.1	6.7	45	8	377	25	0	4
11	52	57	0.00	12.7	12.6	10	18.5	8.8	5.8	0	12 870	4 080	20 350	7.1	2.2	11.2	70	2	478	25	0	3
12	60	54	0.00	12.6	12.8	10	20.6	7.7	6.3	0	14 610	3 720	14 750	8.1	2.1	8.2	—	10	304	25	0	3
13	61	57	tr.	13.8	12.3	10	21.1	7.2	4.7	0	13 375	4 340	9 450	6.8	2.2	4.8	60	12	216	30	0	3
14	68	59	0.00	13.6	12.9	10	20.1	7.5	3.9	0	8 295	4 320	7 820	4.3	2.2	4.0	80	12	134	25	0	3
15	70	61	0.23	13.5	13.2	10	21.2	7.1	6.0	0	11 480	4 260	6 340	5.9	2.2	3.3	62	14	103	34	0	4
16	65	63	0.00	12.4	11.0	10	18.1	7.0	7.8	0	11 500	3 980	3 958	6.5	2.2	2.2	62	21	85	30	0	3
17	63	66	0.00	13.3	13.3	10	21.2	7.1	3.8	0	13 040	5 820	2 522	6.9	3.1	1.3	62	16	68	30	0	4
18	60	65	0.00	14.0	12.8	10	20.5	7.1	3.9	0	14 970	7 250	3 510	7.5	3.6	1.8	55	17	53	30	0	2
19	60	66	0.00	13.5	13.2	10	21.3	7.1	6.5	0	17 929	8 250	5 230	9.3	4.3	2.7	41	13	46	25	0	3
20	57	62	0.99	13.3	12.3	10	21.7	7.0	5.8	0	18 201	7 945	4 580	9.6	4.2	2.4	42	11	40	20	0	3
21	58	63	0.11	12.9	12.7	10	19.0	7.0	5.3	0	16 512	7 255	7 060	9.0	3.9	3.8	42	12	53	20	0	3
22	60	62	0.00	12.3	12.2	10	20.2	7.0	4.9	0	13 980	7 350	7 494	7.9	4.2	4.3	42	10	53	20	0	3
23	60	62	0.00	13.3	10.8	10	19.1	7.0	4.7	0	13 620	7 890	6 748	7.2	4.1	3.5	55	9	63	20	0	3
24	61	61	0.00	12.6	13.1	10	20.6	7.0	4.8	0	12 920	6 690	5 684	7.2	3.7	3.2	52	8	50	15	0	3
25	61	62	0.07	13.3	13.3	10	19.3	7.0	8.6	0	13 720	7 170	4 774	7.2	3.8	2.5	38	8	48	15	0	3
26	66	63	0.10	14.7	13.3	10	20.8	7.2	8.3	0	16 706	8 130	4 354	7.9	3.9	2.1	40	12	48	15	0	3
27	69	62	0.08	15.8	13.2	10	21.6	8.5	7.3	0	16 829	9 390	3 442	7.4	4.2	1.5	52	13	48	15	0	3
28	65	65	0.00	15.1	13.9	10	22.6	8.1	4.9	0	17 637	8 730	2 062	8.2	4.0	1.0	40	12	36	10	0	3
29	69	68	0.00	15.0	13.8	10	21.7	8.0	2.2	0	18 008	8 400	2 088	8.4	3.9	1.0	46	12	59	10	0	3
30	68	66	0.57	12.0	10.7	10	15.8	8.0	5.5	0	14 380	5 490	2 292	8.4	3.2	1.3	47	12	101	10	0	4
31	72	66	0.00	13.6	12.2	10	17.3	7.0	4.2	0	11 915	5 880	3 444	6.1	3.0	1.8	57	13	108	30	0	4
Av.	60	60	....	13.2	12.4	10	20.1	7.6	5.5	..	13 206	6 459	7 173	7.0	3.4	3.9	53	11	196	28	0	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for May, 1909.

Analytical Results, in Parts per Million.																		Bacteriological Tests.							
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.				
																					River water.		Filtered water.		
																					1 c. c.		1 c. c.		50 c.c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
140	110	90	65	91	86	48	39	10	0	0	24	49	24	42	26	16	8	87 500	1 150	560	0	0	0	0	0
92	112	115	100	62	112	40	41	0	0	0	12	30	0	75	59	11	10	86 000	2 000	600	+	+	0	0	0
89	117	105	114	70	115	47	49	0	0	0	6	19	2	58	65	10	7	32 000	2 800	475	0	+	+	0	+
121	128	88	123	82	85	56	58	0	0	0	0	39	43	32	65	12	6	30 000	4 200	675	+	+	0	0	+
167	103	101	114	97	60	65	51	0	0	0	0	70	43	36	63	12	5	18 500	7 500	500	+	+	0	0	+
187	100	95	98	110	81	65	50	0	0	0	4	77	18	30	48	15	7	15 600	8 200	2 000	+	+	0	0	0
202	85	86	92	122	61	58	55	9	0	0	10	81	24	28	37	13	8	6 100	6 750	2 600	+	0	0	0	0
209	74	64	69	127	52	44	44	0	0	0	24	82	22	20	25	16	7	3 200	7 500	5 850	+	+	0	0	0
218	83	69	67	131	51	48	42	0	0	0	22	87	32	21	25	16	7	2 000	2 600	1 600	0	0	0	0	0
160	74	64	69	105	63	41	38	7	0	0	16	56	11	23	32	13	6	29 400	4 900	1 300	+	+	0	0	0
94	141	75	74	67	113	46	33	27	0	0	8	27	28	29	42	9	7	77 000	16 400	1 050	0	+	0	0	0
95	124	106	93	72	107	51	33	51	0	0	6	22	17	55	60	7	5	35 000	36 500	1 275	+	+	0	0	0
115	105	105	98	83	91	68	40	27	0	0	14	32	14	37	57	9	4	24 400	250	50	+	+	0	0	0
118	108	93	83	91	74	56	49	8	10	3	46	27	34	37	34	10	4	13 750	200	275	+	+	0	0	0
164	113	83	74	103	80	51	46	2	0	1	45	61	32	32	28	12	6	3 500	175	100	+	+	0	0	0
191	112	92	83	111	59	53	39	9	0	0	22	80	52	39	41	11	6	2 100	850	425	+	+	0	0	0
215	105	100	85	123	60	52	35	8	8	0	30	92	45	48	50	16	6	1 400	2 000	1 000	+	0	0	0	0
232	109	100	86	135	61	53	36	0	0	1	35	98	48	47	50	15	8	1 500	1 600	600	+	+	0	0	0
242	100	98	86	140	58	54	36	18	0	0	34	102	43	44	50	17	8	1 200	1 500	550	+	+	0	0	0
248	108	116	90	145	63	57	37	3	1	0	30	103	44	59	53	19	8	1 300	1 000	250	0	+	0	0	0
246	98	97	78	140	57	56	37	21	6	0	30	106	41	41	41	17	7	2 100	200	110	0	+	0	0	0
255	97	110	86	146	56	59	30	8	19	0	26	109	40	51	56	18	7	3 250	125	110	+	+	0	0	0
222	93	98	90	131	71	46	27	27	2	0	24	91	22	52	63	19	10	7 400	110	10	+	+	0	0	0
218	94	76	79	135	67	56	30	17	4	0	24	83	27	20	49	15	9	4 100	75	45	+	0	0	0	0
228	93	91	71	144	67	58	33	1	8	0	32	84	26	33	37	20	8	2 650	85	48	0	+	0	0	0
234	100	90	75	142	63	58	38	1	0	0	34	92	37	33	37	19	9	1 100	50	38	+	+	0	0	0
223	89	96	67	139	67	63	39	1	0	1	38	84	21	33	27	17	9	1 250	35	20	+	+	0	0	0
239	84	82	65	153	50	56	41	4	0	4	37	86	34	26	24	17	8	2 300	74	38	0	0	0	0	0
249	97	90	73	160	62	56	43	4	0	1	42	89	34	34	30	22	11	3 300	120	21	0	+	0	0	0
217	79	83	69	142	58	59	44	18	0	0	38	75	21	25	25	16	9	4 570	158	65	+	+	0	0	0
203	82	86	70	128	60	58	42	2	6	0	40	75	23	27	28	16	9	2 100	100	24	+	+	0	0	0
188	101	92	83	117	71	54	40	9	2	0.3	24	71	29	38	43	15	7	16 309	3 523	718	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water. Pumped, million gal.	Volume of Water. Filtered, million gal.	Filter Data. Number used.	Filter Data. Hours in service, average.	Filter Data. Loss of head, maximum, in feet.	Filter Data. Wash-water, percentage.	Filter Data. Use of air.	Applied Chemicals. Pounds. Lime.	Applied Chemicals. Pounds. Soda ash.	Applied Chemicals. Pounds. Coagulant.	Applied Chemicals. Grains per gallon. Lime.	Applied Chemicals. Grains per gallon. Soda ash.	Applied Chemicals. Grains per gallon. Coagulant.	Color. River water.	Color. Filtered water.	Turbidity. River water.	Turbidity. Settled water.	Turbidity. Filtered water.	Free carbonic acid, river water.
1	74	69	0.00	15.1	14.3	10	19.0	6.6	1.7	0	15 705	6 720	3 328	7.3	3.1	1.5	67	12	100	5	0	3
2	72	72	0.25	14.3	12.9	10	19.6	7.4	3.1	0	14 310	6 180	2 796	7.0	3.0	1.4	62	15	65	5	0	3
3	70	70	0.01	14.6	13.1	10	18.1	8.0	1.4	0	14 786	5 803	2 700	7.1	2.8	1.3	60	16	53	5	0	4
4	71	71	0.07	14.9	13.0	10	20.7	8.0	1.6	0	13 568	5 522	2 292	6.4	2.6	1.1	57	15	51	5	0	3
5	70	72	0.07	13.2	13.1	10	19.1	6.5	3.4	0	14 336	5 150	1 964	7.6	2.7	1.0	45	16	46	5	0	3
6	69	70	0.00	11.2	10.7	9	17.1	6.3	2.2	0	11 799	3 248	6 588	7.4	2.0	4.1	75	19	254	5	0	2
7	76	71	tr.	13.3	13.6	10	20.6	7.8	1.5	0	9 153	0	9 636	4.8	0	5.1	87	15	283	5	0	3
8	75	72	0.67	14.7	13.6	10	19.9	7.9	5.0	0	11 908	0	7 440	5.7	0	3.5	100	16	182	25	0	3
9	70	72	tr.	13.2	13.7	9	21.4	7.9	4.1	0	11 000	0	5 088	5.8	0	2.7	100	15	154	25	0	3
10	70	72	0.24	12.6	12.3	9	19.8	8.0	2.2	0	10 980	0	5 520	6.1	0	3.1	62	17	108	25	0	3
11	69	71	tr.	13.8	13.1	9	21.9	8.9	2.9	0	13 080	0	4 968	6.6	0	2.5	67	17	121	25	0	3
12	69	67	0.00	13.7	13.1	9	20.4	7.9	1.8	0	11 760	1 835	5 016	6.0	0.9	2.6	75	17	142	25	0	3
13	73	72	0.00	12.1	11.0	9	18.9	7.9	4.7	0	9 780	2 841	3 720	5.7	1.6	2.1	82	18	102	25	0	3
14	75	72	0.00	13.2	14.3	9	22.1	8.0	2.3	0	11 040	2 985	3 504	5.8	1.6	1.9	100	26	89	25	0	3
15	66	72	0.00	15.0	14.0	9	22.4	8.0	3.3	0	12 495	3 277	3 840	5.8	1.5	1.8	110	26	51	25	0	3
16	70	74	0.00	13.2	13.9	9	23.0	8.0	1.6	0	11 865	2 587	3 382	6.3	1.4	1.8	90	32	35	25	0	3
17	68	71	0.30	14.3	13.8	9	21.5	7.6	1.7	0	12 915	2 730	3 631	6.3	1.3	1.5	94	28	31	25	0	3
18	62	70	0.00	14.0	13.1	9	22.1	7.9	2.2	0	13 005	2 743	2 277	6.5	1.4	1.1	110	35	26	25	0	3
19	63	69	0.00	13.3	14.2	9	22.4	5.7	0.8	0	12 810	2 886	1 764	6.7	1.5	0.9	105	30	25	25	0	3
20	71	71	0.00	12.7	11.3	9	20.8	5.2	1.5	0	12 120	3 029	565	6.7	1.7	0.3	120	25	25	25	0	3
21	74	74	0.32	12.4	13.6	9	22.9	4.9	0.4	0	11 850	3 237	579	6.7	1.8	0 3	135	28	25	12	0	3
22	74	74	0.03	14.7	13.3	9	20.7	7.1	2.6	0	14 205	4 017	889	6.8	1.9	0.4	110	23	23	5	0	3
23	76	74	1.01	14.1	13.7	9	22.3	7.7	5.7	0	14 100	3 998	308	7.0	2.0	0.2	100	18	22	5	0	3
24	77	73	0.12	15.4	13.2	9	22.8	7.0	3.3	0	15 975	5 010	3 871	7.3	2.3	1.8	55	15	89	5	0	3
25	73	73	0.49	14.2	14.4	9	22.2	6.9	1.5	0	16 542	4 891	2 996	8.1	2.4	1.5	40	17	30	5	0	3
26	79	75	0.00	13.6	14.0	9	22.8	5.1	0.6	0	16 126	6 295	3 106	8.3	3.2	1.6	42	17	52	5	0	3
27	80	78	0.23	12.4	11.8	9	19.0	6.9	2.4	0	15 927	6 510	2 978	9.0	3.7	1.7	28	3	36	5	0	3
28	78	78	0.07	14.3	14.6	9	23.1	7.0	2.7	0	16 168	7 620	5 892	7.9	3.7	2.9	40	5	175	5	0	3
29	77	78	0.00	15.7	13.6	9	22.4	7.0	3.2	0	14 259	3 650	5 940	6.4	1.6	2.6	55	3	206	5	0	3
30	74	77	0.00	14.5	14.1	9	21.0	5.0	3.1	0	13 357	0	5 960	6.4	0	2.9	60	5	163	5	0	3
Av.	72	72	....	13.8	13.3	9	21.0	7.1	2.5	..	13 231	3 425	3 728	6.7	1.7	1.9	78	18	92	14	0	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for June, 1909.

Analytical Results, in Parts per Million.																		Bacteriological Tests.							
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.				
																					River water. 1 c. c.		Filtered water. 1 c. c.		Filtered water. 50 c.c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
192	81	78	59	122	64	55	38	2	0	1	36	70	17	23	21	14	7	1 600	40	17	+	+	0	0	0
204	81	82	62	132	55	57	41	3	0	1	40	72	26	25	22	14	6	1 250	105	40	0	0	0	0	0
212	89	80	63	139	56	54	41	0	0	3	38	72	33	26	23	16	5	1 250	50	34	+	+	0	0	0
243	97	103	75	147	52	54	41	0	0	1	40	96	45	49	34	17	6	1 250	65	56	0	+	0	0	0
269	108	93	80	170	44	49	42	0	0	1	40	100	64	44	38	18	9	2 250	150	94	+	+	0	0	0
206	105	95	83	135	59	48	40	23	0	0	38	71	46	47	43	17	10	3 500	142	135	0	+	0	0	0
116	118	101	87	96	68	42	37	10	0	0	34	20	50	59	50	12	10	21 000	275	145	+	+	0	0	0
156	109	102	87	104	52	40	27	4	0	0	24	52	57	62	60	13	10	6 250	90	125	+	+	0	0	0
152	103	92	80	108	53	43	26	1	0	0	20	43	50	49	54	12	7	6 250	45	100	+	+	0	0	0
173	110	92	82	125	48	42	28	0	0	0	26	48	62	50	54	14	8	6 875	—	63	+	+	0	0	0
196	113	99	87	136	47	41	30	0	0	0	28	60	66	58	57	16	7	3 100	60	22	+	+	0	0	0
173	111	105	91	117	54	42	29	8	0	0	26	56	56	63	62	13	8	3 250	27	32	+	+	0	0	0
170	94	100	94	117	61	46	30	0	0	0	28	53	34	54	64	12	8	3 500	48	23	+	+	0	0	0
180	98	91	85	122	59	49	34	0	0	2	48	58	39	42	50	11	7	2 000	50	26	0	+	0	0	0
189	98	88	74	127	57	52	39	0	0	1	38	62	42	36	35	14	8	1 150	60	37	+	0	0	0	0
214	112	98	81	136	53	52	41	0	0	1	40	78	59	46	40	15	9	1 150	35	30	0	+	0	0	0
218	107	103	91	145	51	50	44	0	0	0	32	72	56	52	47	16	9	1 350	55	25	0	+	0	0	0
222	114	112	99	147	50	53	42	0	0	0	32	75	64	60	57	13	8	2 375	75	45	0	+	0	0	0
236	115	114	104	156	49	52	43	0	0	0	30	80	66	62	61	17	10	900	50	34	0	+	0	0	0
237	105	109	108	155	49	48	45	0	0	0	26	82	56	61	63	16	9	850	100	40	0	0	0	0	0
248	99	105	99	158	50	51	45	0	0	0	30	90	50	54	54	16	9	1 075	125	65	0	+	0	0	0
246	105	108	101	159	53	49	45	0	0	0	32	87	52	58	55	16	10	1 875	250	85	+	+	0	0	0
252	110	101	101	163	50	51	43	0	0	0	34	90	59	50	58	18	10	1 125	300	100	+	+	0	0	0
247	96	99	86	159	49	48	41	0	0	0	34	89	47	52	46	16	8	12 500	1 000	235	+	+	0	0	0
260	105	102	94	166	40	44	41	0	0	0	34	94	65	58	53	18	10	3 000	—	250	+	0	0	0	0
257	100	92	92	168	42	37	36	0	0	0	26	89	58	54	56	20	8	7 800	—	1 250	0	+	0	0	+
275	98	93	85	178	50	42	33	0	0	0	22	97	48	51	52	23	7	2 600	25	30	+	+	0	0	0
239	87	81	90	151	42	37	35	2	0	0	20	88	45	44	54	19	9	7 000	1 000	185	+	+	0	0	+
182	78	80	80	120	51	43	32	5	3	0	26	62	27	36	48	14	7	7 500	350	210	0	+	0	0	0
171	104	83	59	121	42	41	30	4	0	2	32	50	62	43	59	14	7	3 000	300	110	+	0	0	0	0
211	102	96	85	139	52	47	37	2	0.1	0.4	32	72	50	49	49	15	8	3 952	180	121	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12—WATER PURIFICATION WORKS.—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water.		Filter Data.					Applied Chemicals.											
											Pounds.			Grains per gallon.			Color.		Turbidity.			
				Pumped, million gal.	Filtered, million gal.	Number used.	Hours in service, average.	Loss of head, maximum, in feet.	Wash-water, percentage.	Use of air.	Lime.	Soda ash.	Coagulant.	Lime.	Soda ash.	Coagulant.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Free carbonic acid, river water.
1	76	77	0.00	14.6	14.3	10	20.2	5.2	3.2	0	13 148	0	5 460	6.3	0	2.6	60	15	121	5	0	3
2	77	77	0.00	14.6	14.7	9	21.5	6.1	3.1	0	13 566	1 740	3 366	6.5	0.8	1.6	70	15	92	5	0	3
3	70	77	tr.	15.0	13.9	9	20.5	6.1	2.9	0	13 756	2 805	2 800	6.4	1.3	1.3	60	18	67	5	0	3
4	67	73	0.00	12.7	11.8	9	16.2	6.1	3.4	0	12 464	1 419	2 218	6.9	0.8	1.2	60	21	50	5	0	3
5	67	73	0.09	12.3	11.8	9	17.4	5.0	1.9	0	11 493	1 384	2 004	6.5	0.8	1.1	62	18	42	5	0	2
6	65	69	0.01	13.5	13.0	9	21.2	5.2	2.2	0	13 680	1 568	2 124	7.1	0.8	1.1	56	19	41	5	0	2
7	72	74	0.00	14.0	14.0	9	21.0	4.9	2.5	0	15 647	1 664	2 148	7.8	0.8	1.1	57	22	36	5	0	3
8	71	74	0.00	15.1	13.8	9	21.9	5.0	1.7	0	16 997	1 768	2 352	7.9	0.8	1.1	47	17	37	5	0	3
9	73	75	0.00	16.3	14.6	9	22.8	5.4	1.6	0	18 502	1 912	2 176	7.9	0.8	0.9	50	15	28	5	0	3
10	76	76	0.00	14.9	14.5	9	23.0	5.0	1.5	0	16 895	1 760	2 120	7.9	0.8	1.0	49	15	28	5	0	3
11	75	76	0.16	13.0	11.8	9	18.7	4.9	3.4	0	13 817	1 528	1 576	7.4	0.8	0.8	45	17	28	5	0	3
12	77	76	1.11	14.3	13.5	9	20.5	4.5	2.9	0	15 356	1 600	1 600	7.5	0.8	0.8	45	17	26	5	0	3
13	74	76	0.38	15.0	13.7	9	19.5	3.5	4.9	0	17 453	1 800	1 744	8.1	0.8	0.8	38	15	36	5	0	2
14	74	76	tr.	15.1	14.1	9	20.3	2.8	2.8	0	17 746	1 768	1 648	8.2	0.8	0.8	40	7	25	5	0	3
15	78	78	0.57	14.0	14.6	9	18.4	2.9	2.4	0	16 530	1 648	1 720	8.3	0.8	0.9	44	4	20	5	0	2
16	72	77	0.23	13.7	13.4	9	20.2	3.2	5.1	0	15 162	1 720	2 016	7.7	0.9	1.0	40	[illegible]	30	5	0	2
17	67	73	0.00	13.8	14.3	9	21.9	3.5	3.9	0	14 573	1 640	2 568	7.4	0.8	1.3	42	5	182	7	0	4
18	67	71	0.01	13.5	12.1	9	21.5	4.2	5.7	0	9 908	624	6 419	5.1	0.3	3.3	50	5	309	20	0	8
19	64	71	0.00	14.7	14.6	10	18.5	4.9	5.2	0	11 458	0	8 022	5.5	0	3.8	50	10	314	20	0	4
20	68	72	0.00	14.3	14.0	9	19.2	3.0	2.0	0	11 485	0	8 169	5.6	0	4.0	50	12	256	15	0	3
21	74	74	0.00	14.0	13.8	9	19.2	3.1	2.4	0	11 257	0	6 634	5.6	0	3.3	55	12	182	15	0	3
22	72	73	0.40	14.2	13.4	9	19.3	3.0	3.9	0	12 184	0	5 456	6.0	0	2.7	67	11	142	18	0	3
23	66	70	0.03	13.8	13.5	9	18.8	2.7	2.2	0	11 443	0	6 176	5.8	0	3.1	67	11	108	20	0	3
24	68	69	0.00	14.4	13.8	9	19.1	3.1	2.4	0	12 013	0	6 592	5.8	0	3.2	65	12	91	18	0	3
25	69	72	0.00	11.9	11.4	9	15.5	3.3	3.5	0	10 673	0	5 108	6.3	0	3.0	64	12	74	15	0	4
26	70	74	0.02	13.9	13.6	9	19.2	2.7	3.0	0	12 611	0	4 300	6.3	0	2.2	57	14	57	12	0	3
27	71	75	0.02	13.4	13.1	9	18.7	2.7	2.6	0	11 985	0	3 136	6.3	0	1.6	61	12	55	15	0	3
28	76	75	0.00	14.5	14.1	9	20.0	3.0	4.3	0	12 511	0	3 320	6.0	0	1.6	57	13	52	10	0	4
29	77	78	0.08	14.3	13.9	9	20.2	2.4	4.5	0	13 024	0	3 048	5.4	0	1.5	52	12	44	10	0	3
30	74	77	0.18	15.3	13.8	9	19.0	2.6	3.8	0	15 459	0	3 088	7.1	0	1.4	57	14	39	12	0	4
31	73	77	tr.	13.7	13.5	9	18.9	2.8	3.1	0	13 919	0	2 422	7.1	0	1.2	52	14	39	10	0	3
Av.	72	74	....	14.1	13.6	9	19.8	4.0	3.2	..	13 765	914	3 598	6.8	0.4	1.8	54	13	86	10	0	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for July, 1909.

Analytical Results, in Parts per Million.																		Bacteriological Tests.							
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.				
																					River water.		Filtered water.		
																					1 c. c.		1 c. c.		50 c.c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
176	100	101	78	125	40	39	28	0	1	0	26	51	60	61	50	13	7	1 000	42	46	+	+	0	0	—
189	93	104	93	129	43	39	26	7	1	0	24	60	50	65	67	15	9	1 800	35	15	+	+	0	0	—
188	83	92	86	132	50	44	29	2	4	0	28	57	33	48	57	15	7	1 250	42	8	0	0	0	0	–
192	94	85	72	138	46	48	34	4	2	0	34	54	48	37	37	15	7	700	42	6	+	+	0	0	—
199	98	90	74	143	50	45	34	0	1	0	34	56	47	45	40	18	7	550	33	6	+	+	0	0	—
199	94	87	81	145	48	46	36	2	0	0	34	54	46	41	45	16	9	750	32	20	0	0	0	0	0
213	100	88	80	155	47	47	37	0	0	0	34	59	53	41	43	16	8	650	37	8	0	+	0	0	-
218	95	95	86	154	45	44	36	3	0	0	34	63	50	51	50	15	8	1 000	30	12	+	+	0	0	—
223	94	91	84	161	45	43	35	1	0	1	34	62	49	48	48	18	10	1 000	50	22	+	+	0	0	—
228	98	99	90	160	43	42	34	3	2	2	32	68	56	57	56	16	8	825	70	12	+	+	0	0	—
230	102	87	88	166	47	42	34	0	0	1	34	64	54	55	53	16	8	450	25	3	0	+	0	0	—
238	98	85	88	171	45	44	36	0	0	0	32	67	53	41	52	18	10	4 450	42	10	+	+	0	0	—
244	103	98	91	177	44	42	38	0	0	0	30	67	59	56	52	19	9	3 000	85	44	+	+	0	0	—
254	100	98	92	177	42	40	37	0	0	0	30	77	58	58	55	19	9	1 100	18	2	+	+	0	0	—
249	106	104	96	181	42	38	36	0	0	0	32	68	64	66	60	19	10	1 000	31	4	+	+	0	0	
242	96	96	87	176	40	40	34	2	0	0	34	66	56	56	53	20	11	1 050	23	2	+	+	0	0	—
241	112	100	91	165	41	40	33	0	0	0	32	76	71	60	57	21	10	34 400	52	5	+	+	0	0	0
136	96	98	92	90	50	44	33	0	0	0	30	46	46	54	58	11	11	30 000	115	15	+	+	0	0	0
126	87	92	90	91	31	36	30	0	0	0	28	35	56	56	60	11	8	10 000	68	30	+	+	0	0	0
133	81	82	86	98	30	26	26	0	0	0	16	35	51	57	60	11	7	9 400	40	23	+	+	0	0	0
144	83	79	81	105	28	23	24	0	0	0	10	39	55	56	57	10	7	3 150	50	21	+	+	0	0	0
150	91	86	82	112	40	28	22	0	0	0	10	38	51	58	59	13	6	2 600	50	25	+	+	0	0	0
152	87	81	80	114	41	30	28	9	0	0	20	38	46	51	52	13	8	2 100	44	12	+	+	0	0	—
156	88	87	85	116	41	33	29	0	0	0	22	39	47	54	54	12	7	1 800	42	10	+	+	0	0	—
161	86	86	82	120	39	32	30	0	0	0	22	42	47	55	52	11	7	1 200	20	8	+	+	0	0	—
161	89	89	88	124	39	33	29	1	0	0	22	38	49	56	59	11	7	1 200	25	2	+	+	0	0	—
176	91	95	90	130	41	33	29	1	0	0	24	46	50	62	61	14	7	1 400	36	8	+	+	0	0	—
178	92	92	86	134	41	37	29	0	0	0	26	43	51	55	56	12	7	1 300	25	10	—	+	0	0	—
177	93	88	85	136	41	37	31	0	0	0	28	42	52	52	54	15	7	1 200	27	5	+	—	0	0	—
192	97	91	86	143	41	35	32	0	0	0	26	49	56	56	54	14	8	1 860	35	8	+	+	—	—	—
181	97	94	85	143	42	37	32	12	0	0	28	49	55	58	53	13	8	2 100	46	4	+	+	—	—	—
192	94	92	86	139	42	38	32	2	0.4	0.1	27	53	52	54	54	15	8	4 009	42	13	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS—(*Continued.*)

Day of Month.	Temperature of air, in degrees Fahr.	Temperature of water, in degrees Fahr.	Rainfall, in inches.	Volume of Water. Pumped, million gal.	Volume of Water. Filtered, million gal.	Filter Data. Number used.	Filter Data. Hours in service, average.	Filter Data. Loss of head, maximum, in feet.	Filter Data. Wash-water, percentage.	Filter Data. Use of air.	Applied Chemicals. Pounds. Lime.	Applied Chemicals. Pounds. Soda ash.	Applied Chemicals. Pounds. Coagulant.	Applied Chemicals. Grains per gallon. Lime.	Applied Chemicals. Grains per gallon. Soda ash.	Applied Chemicals. Grains per gallon. Coagulant.	Color. River water.	Color. Filtered water.	Turbidity. River water.	Turbidity. Settled water.	Turbidity. Filtered water.	Free carbonic acid, river water.
1	76	75	0.00	12.5	11.8	9	16.5	2.8	2.2	0	12 124	0	1 884	6.8	0.0	1.1	46	9	28	7	0	3
2	75	77	0.00	13.9	14.6	9	19.6	3.2	2.9	0	12 569	0	1 878	6.3	0.0	0.9	45	11	35	8	0	3
3	76	77	0.00	17.0	14.3	8	19.9	3.7	2.8	0	15 065	0	1 860	6.3	0.0	0.8	45	10	32	5	0	3
4	72	76	0.00	16.0	14.4	8	20.3	4.2	2.8	0	14 825	0	1 548	6.5	0.0	0.7	44	12	26	5	0	2
5	73	76	0.02	15.4	13.6	9	17.6	4.5	3.4	0	14 775	0	1 386	6.7	0.0	0.6	36	9	24	3	0	3
6	71	74	0.00	13.5	14.0	9	16.8	4.0	2.4	0	13 714	0	1 248	7.1	0.0	0.6	28	8	22	3	0	3
7	71	74	0.00	15.9	15.0	9	19.8	3.0	2.7	0	16 262	0	1 350	7.2	0.0	0.6	26	11	22	3	0	3
8	74	76	0.00	13.0	12.3	9	16.8	2.3	2.5	0	13 629	0	1 356	7.3	0.0	0.7	27	8	22	3	0	3
9	82	77	0.00	15.1	15.8	9	22.6	3.0	2.2	0	15 578	0	1 794	7.2	0.0	0.8	24	9	21	1	0	3
10	75	78	0.09	16.8	15.0	9	23.4	4.3	3.8	0	17 510	1 131	1 878	7.3	0.5	0.8	25	9	22	1	0	3
11	—	—	0.00	15.5	15.1	9	22.7	3.0	3.7	0	15 784	1 693	1 740	7.1	0.8	0.8	22	5	21	3	0	3
12	68	75	0.15	15.1	13.7	9	21.2	2.9	3.5	0	15 817	1 776	1 872	7.3	0.8	0.9	22	3	20	2	0	3
13	72	73	0.00	14.6	14.8	8	23.0	3.2	4.7	0	15 014	1 656	1 842	7.2	0.8	0.9	19	3	20	1	0	3
14	77	75	0.23	15.7	14.7	8	23.0	3.9	3.9	0	16 211	1 904	1 974	7.2	0.8	0.9	19	2	21	2	0	4
15	72	76	1.69	13.0	11.9	8	19.1	3.6	3.7	0	14 039	1 632	2 373	7.6	0.9	1.3	30	3	23	2	0	3
16	74	73	0.14	14.5	14.5	9	19.2	4.4	4.0	0	15 869	1 640	4 364	7.7	0.8	2.1	26	3	47	3	0	4
17	70	76	tr.	15.4	14.2	9	19.9	3.6	3.5	0	18 671	1 728	3 423	8.5	0.8	1.6	22	3	30	3	0	3
18	68	75	0.00	14.5	14.0	9	20.0	4.1	3.3	0	17 138	1 772	2 920	8.3	0.9	1.4	25	3	22	3	0	4
19	71	74	0.00	14.3	14.3	9	19.8	3.5	3.2	0	16 473	1 788	2 600	8.1	0.9	1.3	31	2	23	3	0	4
20	73	74	0.00	15.5	14.3	9	19.3	3.7	3.2	0	18 753	2 304	2 480	8.5	1.0	1.1	25	2	23	3	0	4
21	67	72	0.00	16.6	14.5	9	21.0	4.7	2.8	0	18 905	2 496	1 772	8.0	1.1	0.7	29	4	23	3	0	4
22	65	71	0.00	13.7	12.5	9	17.4	4.2	3.6	0	14 096	2 048	1 132	7.2	1.0	0.6	30	3	22	2	0	3
23	62	70	0.00	16.6	15.1	9	20.1	4.5	2.7	0	14 586	2 512	1 288	6.1	1.1	0.5	32	3	21	2	0	4
24	72	71	0.00	16.9	15.1	9	21.2	4.2	2.7	0	15 305	2 536	1 284	6.3	1.0	0.5	32	7	20	2	0	5
25	75	74	0.05	16.1	15.3	9	21.3	4.1	3.3	0	13 754	956	1 264	6.0	0.4	0.5	36	12	20	3	0	4
26	78	76	0.04	15.6	15.0	9	20.2	4.4	4.8	0	12 098	0	1 228	5.4	0.0	0.6	37	11	20	5	0	3
27	80	80	0.09	17.1	15.7	9	22.2	4.6	3.1	0	14 464	464	1 352	5.9	0.2	0.6	32	11	20	10	0	3
28	79	81	0.02	17.6	15.2	9	20.4	6.4	4.3	0	11 611	2 012	1 344	4.6	0.8	0.5	39	14	22	7	0	1
29	74	80	0.01	14.2	12.8	9	17.3	8.0	5.0	0	8 991	1 720	1 164	4.4	0.8	0.6	37	12	22	6	0	0
30	66	75	0.00	15.5	15.4	9	20.9	7.9	3.2	0	11 436	1 768	1 212	5.2	0.8	0.5	37	15	20	5	0	2
31	65	73	0.00	16.3	15.5	8	23.3	7.9	3.0	0	12 708	1 904	1 288	5.5	0.8	0.6	38	17	20	5	0	3
Av.	72	75	....	15.2	14.3	9	20.2	4.3	3.3	..	14 767	1 208	1 810	6.8	0.5	0.8	31	8	24	4	0	3

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for August, 1909.

Analytical Results, in Parts per Million.																		Bacteriological Tests.							
Total hardness.				Total alkalinity.				Caustic alk.				Incrustants.				Magnesium.		Bacteria per c. c.			Presumptive *Coli* tests.				
																					River water.		Filtered water.		
																					1 c. c.		1 c. c.		50 c.c.
River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	Inlet to sett. basin.	Settled water.	Filtered water.	Mono. carb. alk., filtered water.	River water.	Inlet to sett. basin.	Settled water.	Filtered water.	River water.	Filtered water.	River water.	Settled water.	Filtered water.	Smith method.	Bile method.	Smith method.	Bile method.	Smith method.
190	92	95	87	144	40	40	31	3	1	1	30	46	52	55	55	15	8	2 530	43	6	+	—	0	0	0
198	96	84	84	148	42	38	32	8	0	1	32	50	54	46	52	15	7	2 400	25	3	+	+	0	0	0
200	94	88	85	152	40	37	32	0	0	2	30	48	53	51	54	17	8	1 480	21	9	+	—	0	0	0
203	97	92	84	154	41	37	34	0	0	0	30	49	56	55	51	16	9	1 300	43	19	—	—	—	—	0
213	92	91	87	157	39	39	34	0	0	0	30	56	53	52	53	16	10	1 200	66	48	+	—	0	0	0
220	94	95	86	163	37	39	36	0	0	0	30	58	56	56	49	18	11	1 850	43	106	+	+	0	0	0
230	106	103	101	166	39	38	37	0	0	0	30	64	67	65	64	18	11	2 100	85	113	0	0	0	0	0
236	109	105	96	169	38	39	36	0	0	0	28	67	71	67	60	19	10	1 580	44	47	0	0	0	0	0
242	116	103	100	173	42	36	37	0	0	0	26	69	74	67	63	20	10	1 000	11	14	0	0	0	0	0
247	108	106	101	173	37	34	35	0	0	0	24	75	71	71	66	21	11	1 570	7	5	+	+	0	0	0
243	104	103	104	167	39	36	33	0	0	0	26	75	65	67	71	22	11	425	21	4	+	0	0	0	0
237	104	104	99	167	43	39	36	0	0	0	24	70	62	65	64	21	11	2 000	22	6	+	—	0	0	0
248	107	105	99	172	45	43	37	0	0	0	28	76	62	63	62	20	11	1 600	20	12	—	—	0	0	0
245	108	111	101	170	47	46	38	0	0	0	28	75	61	65	63	21	12	900	16	2	0	0	0	0	0
236	110	107	105	163	41	43	39	0	0	0	24	73	69	64	67	20	12	7 800	20	2	+	+	0	0	0
222	96	98	99	159	36	41	38	3	0	0	26	63	60	57	61	19	12	9 000	50	5	+	+	0	0	0
241	97	98	94	168	34	37	34	0	0	0	22	73	64	62	60	20	11	2 500	25	15	+	0	0	0	0
244	102	97	92	169	37	35	32	8	0	0	24	75	66	63	59	22	11	1 350	65	8	+	+	0	0	0
245	100	98	92	172	37	36	28	0	0	0	28	72	63	62	64	21	10	2 500	65	22	0	+	0	0	0
257	106	101	94	182	46	36	30	4	0	0	26	75	60	66	64	22	10	1 600	150	40	+	+	0	0	0
230	96	102	91	163	41	40	30	2	1	0	26	68	55	62	61	21	11	1 400	90	45	+	+	0	0	0
217	91	92	85	149	41	38	30	3	3	3	32	67	51	54	55	20	10	1 500	45	44	+	+	0	0	0
216	96	94	81	147	47	43	31	8	0	5	26	69	49	50	50	20	9	1 300	180	65	+	+	0	0	0
210	92	94	83	147	45	47	36	0	0	0	30	63	46	47	47	18	8	450	2	2	0	+	0	0	0
205	105	95	84	142	57	48	38	0	0	0	30	64	48	47	46	16	10	1 600	200	100	0	0	0	0	0
204	106	103	85	140	45	42	35	0	0	0	30	64	61	61	51	16	10	2 250	165	40	+	0	0	0	0
204	108	113	100	138	43	43	34	3	0	0	28	66	66	70	66	15	10	700	—	35	+	0	0	0	0
182	94	100	92	122	47	44	34	1	0	0	30	60	46	56	58	16	10	800	500	40	+	0	0	0	0
185	106	104	93	118	54	51	35	0	0	0	34	67	51	53	58	15	9	850	300	25	+	0	0	0	0
197	107	97	84	134	57	48	37	0	0	0	34	64	50	48	47	16	10	750	42	31	+	0	0	0	0
197	95	94	91	134	52	48	43	0	0	0	32	63	44	46	48	17	11	250	115	4	+	0	0	0	0
221	101	99	92	156	43	41	35	1.4	0.2	0.3	28	65	58	58	58	19	10	1 888	83	29	....	....	....	....	......

Coagulant = Sulphate of iron or sulphate of alumina.

on August 17th, 1908, a partial supply of filtered water was begun, the filtered water being run by gravity to the old West Side Pumping Station and pumped from there. On October 28th, 1908, the old West Side Pumping Station was shut down, the old East Side Pumping Station having been shut down shortly before, and since this date the city has been supplied entirely with filtered water from the new works. Filtration began regularly on August 19th, 1908, and softening on September 22d, 1908.

The principal contracts for the work were:

Water purification works........	Westwater and Casey.
Machinery and equipment.......	The Holly Manufacturing Company.
Pumping station and connections..	Westwater and Casey.
Cast-iron force mains...........	Westwater and Casey.

Operation.

The daily records of the results of operation of the water purification works for the eight months, January to August, 1909, inclusive, are presented in Table 12. The writer has not been in charge of operation, his direct connection with the works having ceased on January 1st, 1909, and it is, therefore, through the courtesy of the Engineer and Chief Chemist of the works that he is enabled to present these results. A detailed discussion of the methods of operation and of the results is not within the province of this paper, and, therefore, the writer will not enter into this phase of the subject, but hopes that a full discussion may be presented by those having a direct oversight of the works.

The problem of softening and filtering the Scioto River water is an exceedingly complex one, as the water is subject at times to rapid fluctuations in turbidity, color, alkalinity, and incrustants, and in the portion of magnesia serving as a coagulant. Following heavy rains the turbidity rapidly increases while the hardness correspondingly decreases. Further, some of the turbidity in the settling basins is undoubtedly due to precipitates coming from the applied chemicals.

From an examination of the data in Table 12 it will be seen that the river water is an unusually difficult one to handle. While it may be noted that at times somewhat abnormal results have been obtained, such occasional results are to be expected in a plant passing through its first year of service, especially when treating a water similar to that of the Scioto River in reference to which there

was available a very limited amount of information as to the best method of treating the water under variable conditions, as was the case at Columbus when the works were designed. The bacterial removal, as a rule, has been very satisfactory, but in some instances the numbers in the filtered water have been very high, due to bacterial growths in the settling basins, in the filters, or in both.

While, from the experience obtained during the first year of service, it has been found that for greater ease of operation some few modifications would be desirable, the results obtained demonstrate conclusively that the design of the works is a sound one, and that the works are capable of producing a perfectly satisfactory, softened, purified water, suitable in all respects for public water-supply purposes. The quality of the water furnished from the works has given excellent satisfaction among the water consumers, and has caused the abandonment of a large number of rain-water cisterns throughout the city.

II.—THE IMPROVED SEWAGE WORKS.

Before describing the sewage works which have recently been completed at Columbus, it will be well to outline briefly the sewerage system of the city and explain the sewage problem which presented itself for solution.

Sewerage System.—The topography of Columbus is such that, in the collection of the storm-water and dry-weather sewage, the city is divided naturally into three districts: the East Side Sewer District, the Intercepting Sewer District, and the West Side Sewer District. The outline of these districts is shown on Fig. 1.

The East Side District is sewered on the combined system, with an outlet sewer in East Main Street emptying into Alum Creek, which in turn discharges into the Scioto River a few miles below Columbus.

The Intercepting Sewer District is sewered largely on the combined system, the outlets of the numerous main sewers being along the east bank of the Olentangy and Scioto Rivers. The dry-weather flow in the combined system, however, is intercepted and discharged into an intercepting sewer which starts at the north end of the city and runs south along the east bank of the two rivers, the outlet formerly being on the east bank of the Scioto River about $2\frac{1}{4}$ miles below the center of the city.

The West Side District is sewered largely on the separate system, the sewer outlets being along the west bank of the Scioto River. The

dry-weather flow in the combined sewers, however, is intercepted and discharged into the sanitary system.

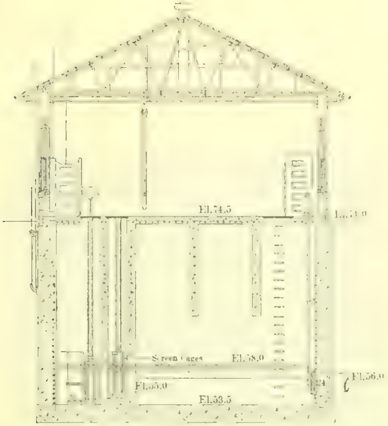
In the West Side District a portion of the ground is low, and, in the past, during periods of high water in the river, some of the sewers have overflowed, flooding certain of the streets and numerous cellars. As previously stated, the discharge of sewage into Alum Creek and the Scioto River during periods of low water had been the cause of offensive conditions.

Outline of Sewage Problem.—It should be mentioned here that no public water supply is taken from the Scioto River below Columbus. At Portsmouth, Ohio, 100 miles from Columbus, where the Scioto discharges into the Ohio River, however, the water supply is taken from the Ohio, but at a point some distance above the junction of the two rivers.

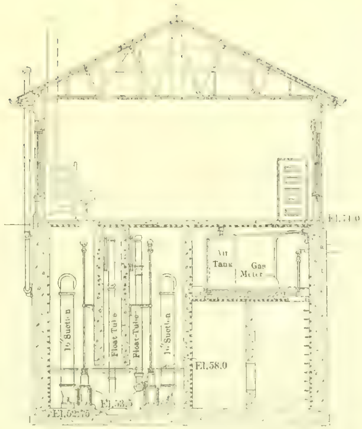
From the brief description of conditions just given, it will be seen that the sewage problem resolved itself first into the elimination of the direct discharge of sewage into Alum Creek and the Scioto River, which could be accomplished by the construction of purification works at one or more points, in which the treatment of the sewage would be such that the effluent, discharged into either Alum Creek or the Scioto River, would at all times be non-putrescible, and second, the prevention of the overflowing of the sewers on the west side.

Preliminary Investigations.—The first step taken toward the solution of the sewage problem was a joint investigation made by Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the Department of Public Improvements, and John W. Alvord, M. Am. Soc. C. E., Consulting Engineer. Their report, which was made in May, 1898, was based on the best information then available, and the several projects which they studied involved all the well-known methods of purification which had received consideration, not only in the United States, but in England. Their recommendation, in brief, besides extensions and improvements to the sewerage system and the construction of pumping stations necessary to deliver the dry-weather sewage at the purification works, was the screening of the sewage and its double filtration through coke at a net rate of 500 000 gal. per acre per 24 hours. The works proposed were to treat 20 000 000 gal. of sewage per 24 hours, but it was advised that only 2 acres of the coke beds, practically contact filters, be built at the start, and that these beds be then operated for a year under

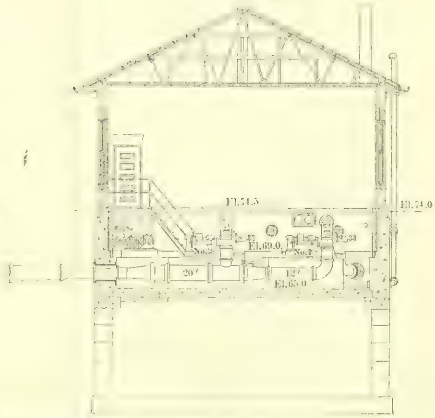
PLATE XVI.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



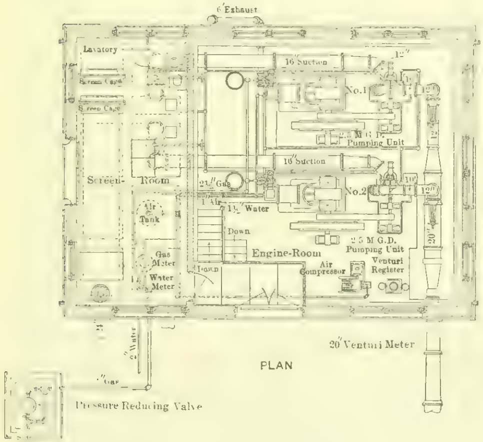
SECTION THROUGH SAND-CATCHER



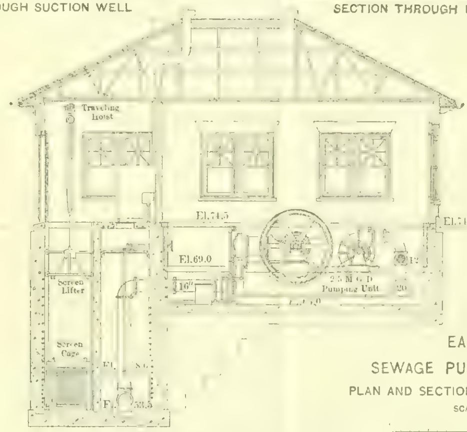
SECTION THROUGH SUCTION WELL



SECTION THROUGH ENGINE-ROOM



PLAN



SECTION THROUGH SCREEN-ROOM AND ENGINE-ROOM

EAST SIDE
SEWAGE PUMPING STATION
PLAN AND SECTIONS SHOWING MACHINERY

SCALE OF FEET

expert supervision, after which, from the practical experience gained, the remaining beds were to be constructed.

No further action was taken, after the submission of the report by Messrs. Alvord and Griggs, until 1901, when Mr. Rudolph Hering was asked to review the whole sewage problem. In May, 1901, Mr. Hering reported in favor of the construction of septic tanks followed by intermittent filtration through sand, endorsing also the previous recommendation that a portion only of the works be constructed at first and operated for a period of at least one year before designing and constructing the remainder. Mr. Hering also endorsed the recommendations made by Messrs. Alvord and Griggs relative to the construction of pumping stations and the revisions and extensions of the sewerage system. It was not until November, 1903, however, that the first funds were provided so that the carrying out of the sewage improvements was assured.

Experimental Investigation.—From the previous investigations and studies, the general character and scope of the various parts of the improvement had been reasonably well outlined, but the engineers were confronted with the problem of designing a purification works a part of which was to be built and operated experimentally for a year, and which must be arranged so as to fit in as an integral part of the permanent construction. After further thought and study, it was concluded that it would be a wiser plan to make an extended experimental investigation, on a practical scale, of the various methods of sewage purification, for a period of at least one year, in order to determine the most efficient and economical method, and then to design the purification works accordingly. The co-operation of the City Council was therefore asked, and it very generously responded by appropriating the sum of $46 000 for experimental purposes. Immediately following this appropriation, a sewage testing station was designed and built, in which, from August 16th, 1904, to July 30th, 1905, various methods of sewage purification were studied exhaustively. As it is not the purpose of this paper to discuss the results of this investigation, a full report of which has already been published,* it will be sufficient to state the indications of the experimental work, namely, that, under the local conditions, the Columbus sewage could be treated most satisfactorily and economically in a purification works comprising septic tanks,

* Report on Sewage Purification at Columbus, Ohio, 1905, by George A. Johnson, Assoc. M. Am. Soc. C. E.

sprinkling filters, and settling basins, and this method was therefore adopted. While the investigation showed that satisfactory results could be obtained by preliminary clarification and subsequent filtration through sand, it also showed, for the first time in the United States, that sprinkling filters could be operated in a northern climate and produce a satisfactory effluent at less cost than any other type of filter.

Brief Outline of Works.—The preliminary investigations made by Messrs. Griggs, Alvord, and Hering, and subsequent ones made by the engineering organization, indicated that it would be most advisable and economical to build and operate one purification works rather than two, and that the most feasible site for the works was on the Scioto River south of the city.

Briefly stated, the dry-weather flow of the whole city is brought to one point, where a pumping station, known as the Main Sewage Pumping Station, has been built. To accomplish this result, it has required the construction of a small pumping station near Alum Creek, known as the East Side Sewage Pumping Station, where the sewage from the East Side Sewer District is intercepted and pumped through a force main discharging into the upper end of one of the main sewers in the Intercepting Sewer District, the extension of the intercepting sewer across the Scioto River, and the construction of a new sanitary sewer connecting with the West Side Sewer District, and the reconstruction of a portion of the sewerage system in that district. From the Main Sewage Pumping Station the sewage is pumped through a force main to sewage purification works where the sewage is treated, the effluent from the works passing into the Scioto River. The Main Sewage Pumping Station is also arranged to pump storm-water from the West Side, one of the storm-water sewers having been extended to the pumping station. In addition, the work has included about 2.55 miles of levee construction, a railroad spur, 1.85 miles in length, and a single-track railroad bridge across the Scioto River. The location of the various parts of the work are shown on Fig. 1.

East Side Sewage Pumping Station and Force Main.

The East Side Sewage Pumping Station is located on the south side of East Main Street and about 400 ft. west of Alum Creek. A general plan of the station and connections is shown on Fig. 13, and the detail of the pumping station on Plate XVI.

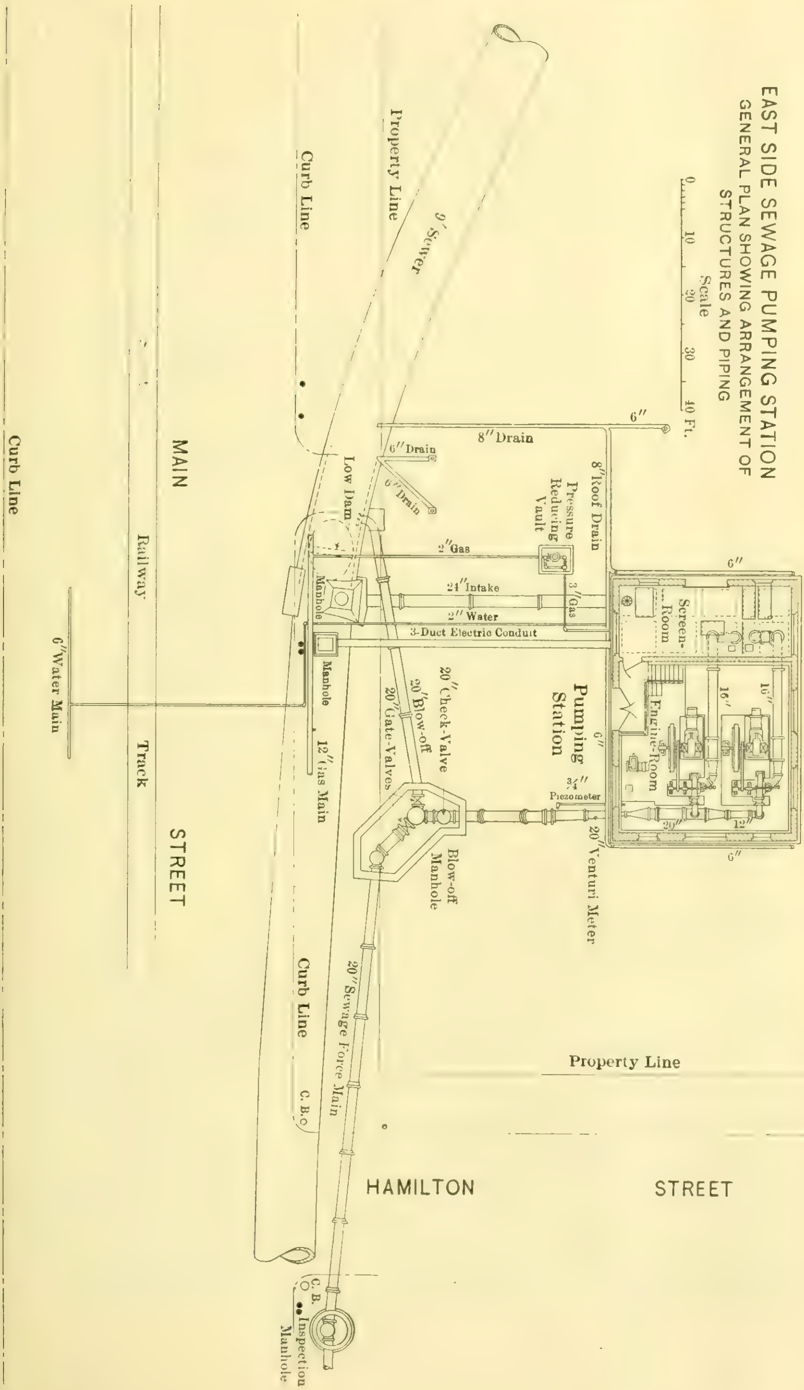

EAST SIDE SEWAGE PUMPING STATION
GENERAL PLAN SHOWING ARRANGEMENT OF
STRUCTURES AND PIPING
Scale
0 10 20 30 40 Ft.
Property Line
Curb Line
9′ Sewer
8″ Drain
6″ Drain
6″ Drain
8″ Roof Drain
Pressure Reducing Vault
Low Dam
2″ Gas
24″ Intake
2″ Water
3″ Gas
3-Duct Electric Conduit
Manhole
Manhole
Screen-Room
Engine-Room
Pumping Station
20″ Check-Valve
20″ Blow-off
20″ Gate-Valves
¾″ Piezometer
20″ Venturi Meter
Blow-off Manhole
12″ Gas Main
6″ Water Main
MAIN
Railway
Track
STREET
Curb Line
20″ Sewage Force Main
Property Line
C. B.
HAMILTON
STREET
Inspection Manhole

FIG. 13.

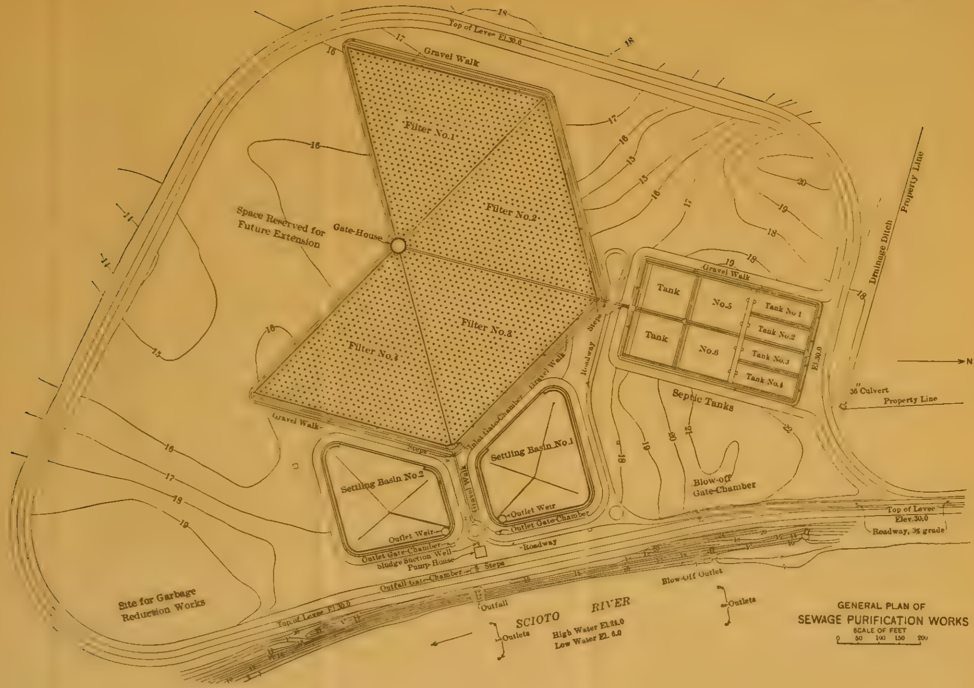
Connections.—Passing in front of the pumping station there is a 9-ft. combined sewer which serves as the outfall sewer for the East Side Sewer District. A low dam constructed in the bottom of this sewer intercepts the dry-weather flow and first wash of the storm flow, diverting it into a 24-in. intake pipe connecting with the substructure of the pumping station. Connections are also made with the water main and high-pressure natural-gas main in the street. The electric light and telephone wires are brought in through a three-duct vitrified conduit.

Substructure.—The sewage is first admitted to a long chamber, serving as a sand-catcher, is screened to remove the coarser matters in suspension, and then passes into the suction well. The screening device consists of two cages, of steel-frame construction, holding removable sets of screens made up of ¾-in. square bars, 1 in. apart in the clear. The cages are raised and lowered by hand by a movable screen lifter hung from a traveling hoist and runway just below the ceiling of the screen-room above. The substructure is of concrete, reinforced at various points. In the substructure of the engine-room, in which it was necessary to locate the pumps and engines on account of the suction lift, the walls are lined with hard vitrified red pressed brick.

Superstructure.—The walls of the superstructure are of brick, faced outside with red pressed brick. In the engine-room the walls are lined with light-buff speckled pressed brick, and in the screen-room with hard red brick. The stone trimmings are all of Bedford, Ind., limestone. The ceilings in both rooms are of plaster on metal lath fastened to the lower chords of the roof trusses. The roof is of 3-in. hollow terra cotta tile and slate carried by steel trusses and intermediate framing.

Pumping Machinery.—The pumping machinery is installed in duplicate. Each unit consists of a Columbus, horizontal, four-stroke-cycle, gas engine, connected by a Morse, silent-running, high-speed chain to a horizontal, single-stage, Worthington, volute pump with 12-in. suction and 10-in. discharge nozzles. The engine is capable of developing 90 h.p. when operating on natural gas having a thermal value of about 1 000 B. t. u. per cu. ft. When running together each unit has a rated capacity of 2 200 000 gal. per 24 hours against a head of 75 ft., and when running alone a maximum capacity of 2 900 000 gal. per 24 hours against a head of 63 ft. For starting the engines, the equipment includes a small motor-driven air compressor and air tank.

PLATE XVII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



GENERAL PLAN OF
SEWAGE PURIFICATION WORKS
SCALE OF FEET
0 50 100 150 200

Force Main.—The sewage is pumped through a 20-in- cast-iron force main to a point about 8 180 ft. from the pumping station where it is discharged into the upper end of the Mound Street Sewer, this sewer in turn discharging into the intercepting sewer on the east bank of the Scioto River. The flow is measured by a 20-in. Venturi meter, the register, chart recorder, and manometer being placed in the pumping station. The meter tube is of special construction, and between the tube and the register and manometer, oil seals are interposed to keep the sewage out from the latter.

Levees, Railroad Spur, and Bridge.

The sites chosen for the main sewage pumping station and for the purification works, while possessing many advantages, were not readily accessible for the delivery of materials, not being near a railroad, and the Scioto River not being a navigable stream. In considering the cost of the work, it was seen that a large expense would be incurred in hauling construction materials, for which there would be no apparent return. It was decided, therefore, that it would be economical in the long run to build a permanent railroad spur connecting with the main line of the Hocking Valley Railway, over which cars could be switched directly to the sites of the two works.

The ground near the river south of the city is relatively low, and during high floods was sometimes submerged, the river overflowing the old existing levees. In order that the railroad spur might at all times be above high water, new levees have been constructed, on which the spur has been built. The levees, therefore, serve the double purpose of providing an excellent location for the spur and of protecting a large amount of property. The city was especially interested in building the levees, as it is the owner of a large tract of the land which was sometimes submerged.

Levees and Railroad Spur.—The spur starts at the Hocking Valley Railway, at the foot of Moler Street, and extends southwest to a point where it crosses the river by a bridge, after which it follows south along the west bank of the river past the pumping station and down to the purification works. The total length of the spur is 1.85 miles. The levees have a top width of 16 ft. and side slopes of 1.5 horizontal to 1 vertical, are about 13 ft. above the general level of the ground, and were built of a mixture of loamy and sandy material obtained along the line. At several points the levees are pierced by small con-

crete culverts, the outlets at the river bank being protected by flap-valves.

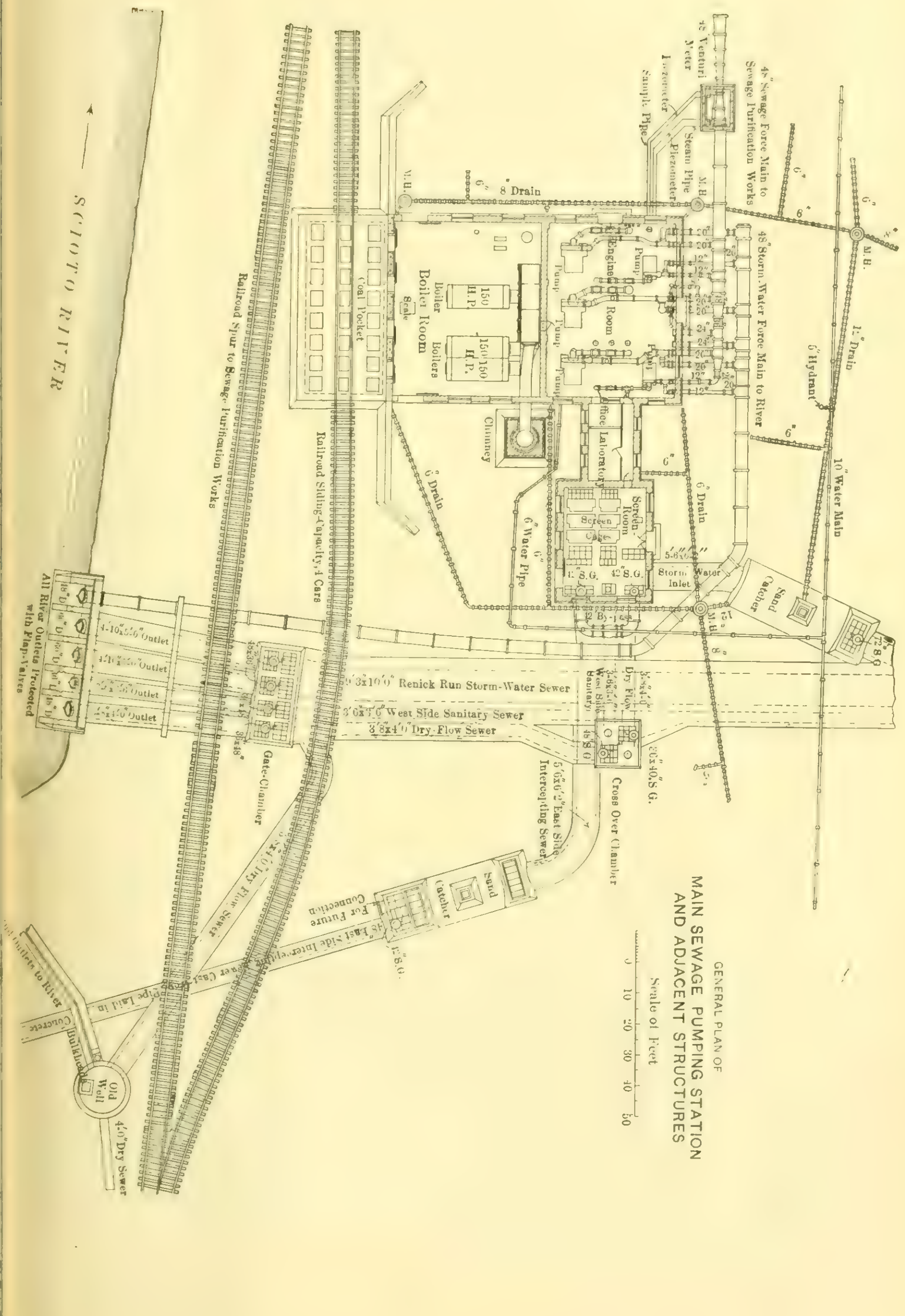
Bridge.—The spur is carried across the river by a single-track through bridge, consisting of three spans, 150 ft. 6 in. in length, or a total of 457 ft. 6 in. from center to center of end pins. The substructure consists of two abutments and two piers of concrete supported on timber piles. The abutments have a total height of 32 ft. 8 in. and the piers a height of 34 ft. The superstructure consists of steel, pin-connected, Pratt trusses, designed for a live load corresponding to Cooper's Class *E* 40 loading. The bridge has a clear width of 14 ft. between trusses and a clear height of 22 ft. above the base of the rails. The timber floor is carried on four track stringers.

Sewer, Water, and Gas Main Extensions.

Intercepting Sewer.—The intercepting sewer, which drains the greater part of the built-up portion of the city, formerly discharged on the east bank of the river. This sewer has been extended across under the river a distance of about 540 ft. to a sand-catcher connected with the Main Sewage Pumping Station. The extension consists of a 48-in. cast-iron pipe surrounded by concrete. On the east bank, just back of the connection with the old sewer, a relief outlet has been provided which will open automatically if the flow of sewage is shut off at the sand-catcher or at the pumping station.

West Side Sanitary Sewer.—In order to bring the dry-weather flow of sewage from the west part of the city to the pumping station, a new sewer, 1.85 miles in length, called the West Side Sanitary Sewer, has been built. For a portion of the way the sewer is of brick and concrete, but, from the point where it is built in connection with the Renick Run Storm-Water Sewer, it is entirely of concrete. At the upper end its diameter is 3 ft., enlarging farther down to 3 ft. 6 in., and the concrete section, in connection with the storm-water sewer, is 3 ft. 6 in. by 3 ft. 6 in., with vertical side-walls. An outlet to the river has been provided, and, where this sewer joins with the storm-water sewer, a sand-catcher and relief outlet have been built. In order to divert the flow of sewage to this new sewer, certain reconstruction of the sewerage system in the west part of the city has been necessary.

Renick Run Storm-Water Sewer.—The storm-water from a part of the west side of the city is carried away by the Renick Run Storm-



GENERAL PLAN OF
MAIN SEWAGE PUMPING STATION
AND ADJACENT STRUCTURES

Water Sewer which discharged formerly into the Renick Run Ditch, on the property of the city, about 3 050 ft. west of the pumping station. This sewer has been extended to the pumping station and river. The sewer is of concrete, with vertical side-walls, is 8 ft. by 7 ft. 4 in. enlarging to 10 ft. by 9 ft. 3 in., and is built in connection with the West Side Sanitary Sewer. There is a sand-catcher on the branch leading to the pumping station. At the Renick Run Ditch, there is also a relief which will come into play if, for any reason, the pumping station should cease pumping storm-water during a period of high water in the river.

Dry-Flow Sewer.—A portion of the sanitary sewage from the West Side is also carried by the old 4-ft. Dry-Flow Sewer. This sewer, although at present in bad shape, has been extended to the pumping station and a new outlet to the river provided. With additional extensions of the sewerage system in the city, it is proposed to abandon it as a sanitary sewer and use it only for storm-water.

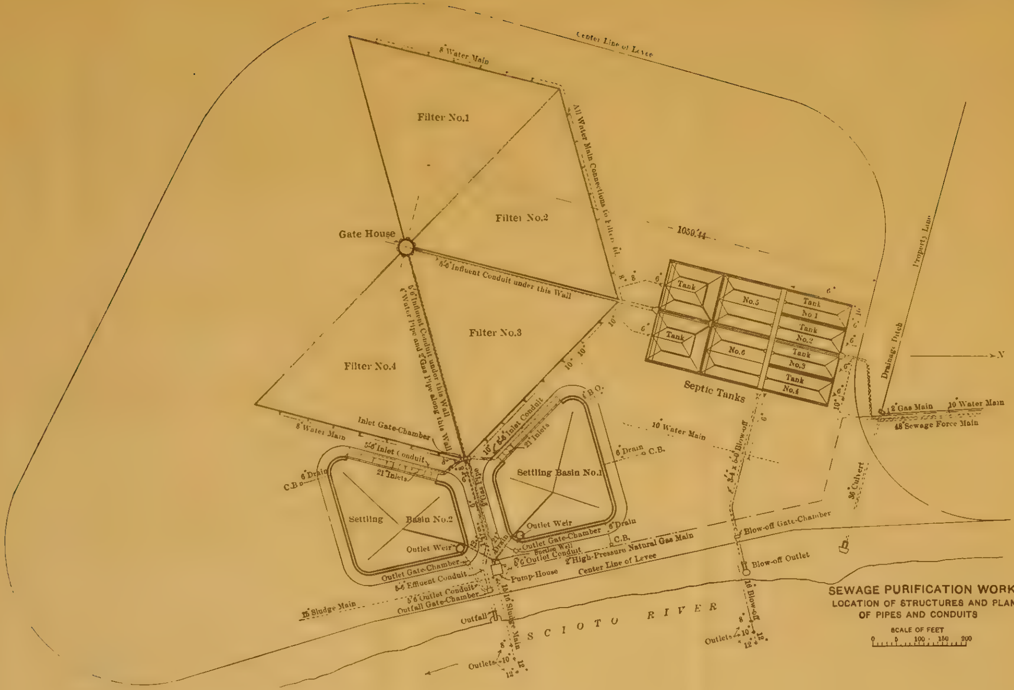
Water Main.—To provide a suitable water supply under pressure at the pumping station and purification works, it has been necessary to lay a 10-in. water main, 2.05 miles in length, connecting with the distribution system in the city at the corner of High Street and Neff Avenue.

Gas Main.—For supplying natural gas for light and power at the sewage purification works, a 2-in. high-pressure gas main, 1.65 miles in length, has been laid from the high-pressure gas main of the Federal Gas Company in Stimmel Road to the purification works.

Main Sewage Pumping Station.

The Main Sewage Pumping Station is on the west bank of the Scioto River about 2¼ miles south of the center of the city. Fig. 14 shows the location of the pumping station and connections, and the structures immediately adjacent. Although the station is protected from the river by the new levee, it was considered wise, as an additional safeguard, to enclose the pumping station lot with a levee also. The levee around the lot has the same dimensions as the levees on which the railroad spur is built, but this levee and that back of the station immediately adjacent to the river were built with carefully selected materials placed in layers and well rolled. The general arrangement of the machinery and equipment, and sections through the building, are shown on Fig. 15.

PLATE XVIII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



SEWAGE PURIFICATION WORKS
LOCATION OF STRUCTURES AND PLAN
OF PIPES AND CONDUITS

SCALE OF FEET
0 50 100 150 200

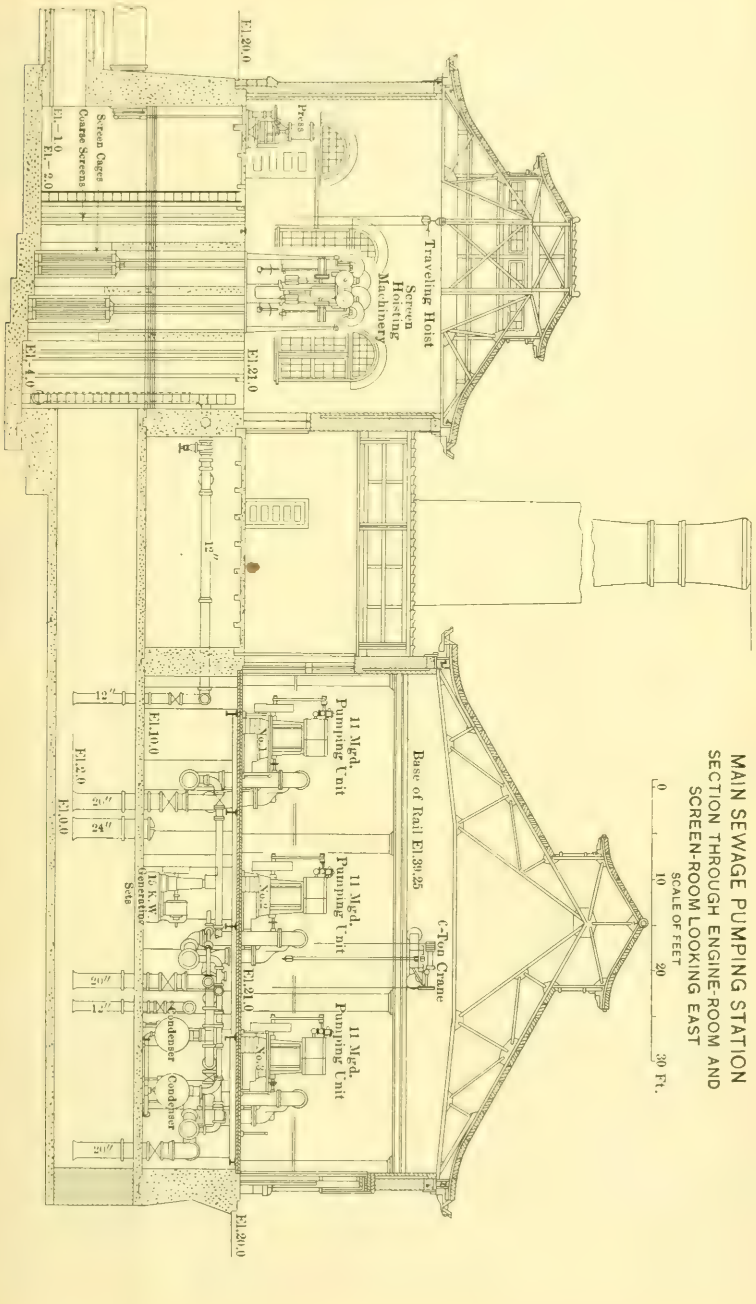

MAIN SEWAGE PUMPING STATION
SECTION THROUGH ENGINE-ROOM AND
SCREEN-ROOM LOOKING EAST
SCALE OF FEET
0
10
20
30 Ft.
El.20.0
Press
Screen Cages
Coarse Screens
El. -1.0
El. -2.0
Traveling Hoist
Screen
Hoisting
Machinery
El.21.0
El.-4.0
12″
El.151.
Base of Rail El.39.25
6-Ton Crane
11 Mgd.
Pumping Unit
No.1
No.2
No.3
El.10.0
El.2.0
El.0.0
12″
20″
24″
15 K.W.
Generating
Sets
Condenser
El.21.0
El.20.0

Fig. 15.

Connections.—The connections to the pumping station are shown on Fig. 14, and need but little description. The sanitary sewage, and the storm-water when it is necessary to pump it, first flows into the substructure under the screen-room, where it is screened, then passes into the suction wells and is pumped out through either or both of the force mains. One force main, for the sanitary sewage, leads to the purification works, about 1.2 miles away, and the other, for the storm-water, leads to the river directly back of the pumping station.

Building.—The substructure consists principally of screen chambers and of a basement under the engine-room. Below the basement there are three suction wells, one for the East Side sanitary sewage, one for the West Side sanitary sewage, and the third for the West Side storm-water. By means of a by-pass outside of the screen chambers, any one or all of the wells can be used. The substructure is entirely of concrete, reinforced at points.

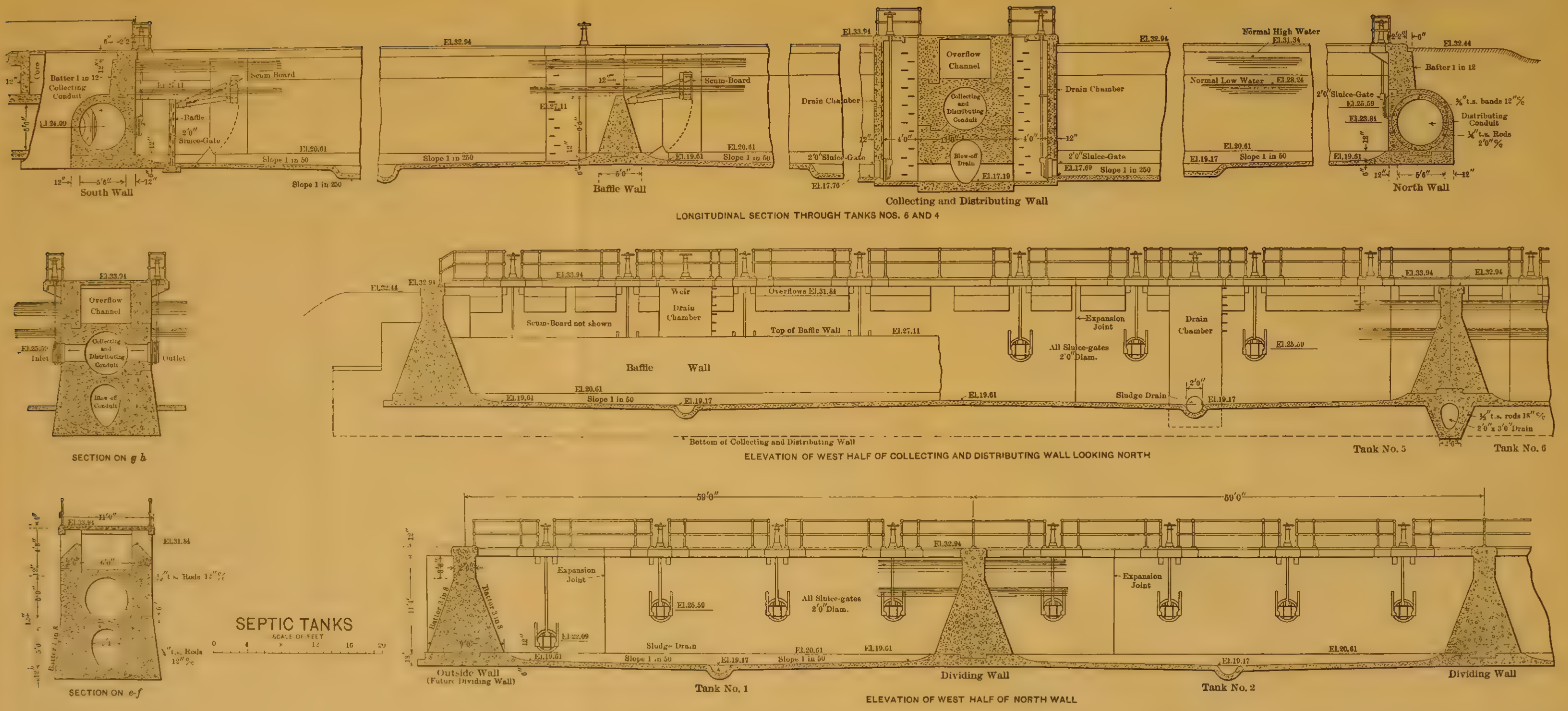
The superstructure consists of a screen-room, engine-room, boiler-room, office, lavatory, and coal pocket. The building proper is of brick and the coal pocket of concrete, the type of construction in both cases being in general similar to that of the Scioto River Pumping Station, already described. The coal pocket has a capacity of 380 tons, or about 40 days' supply at the present rate of consumption.

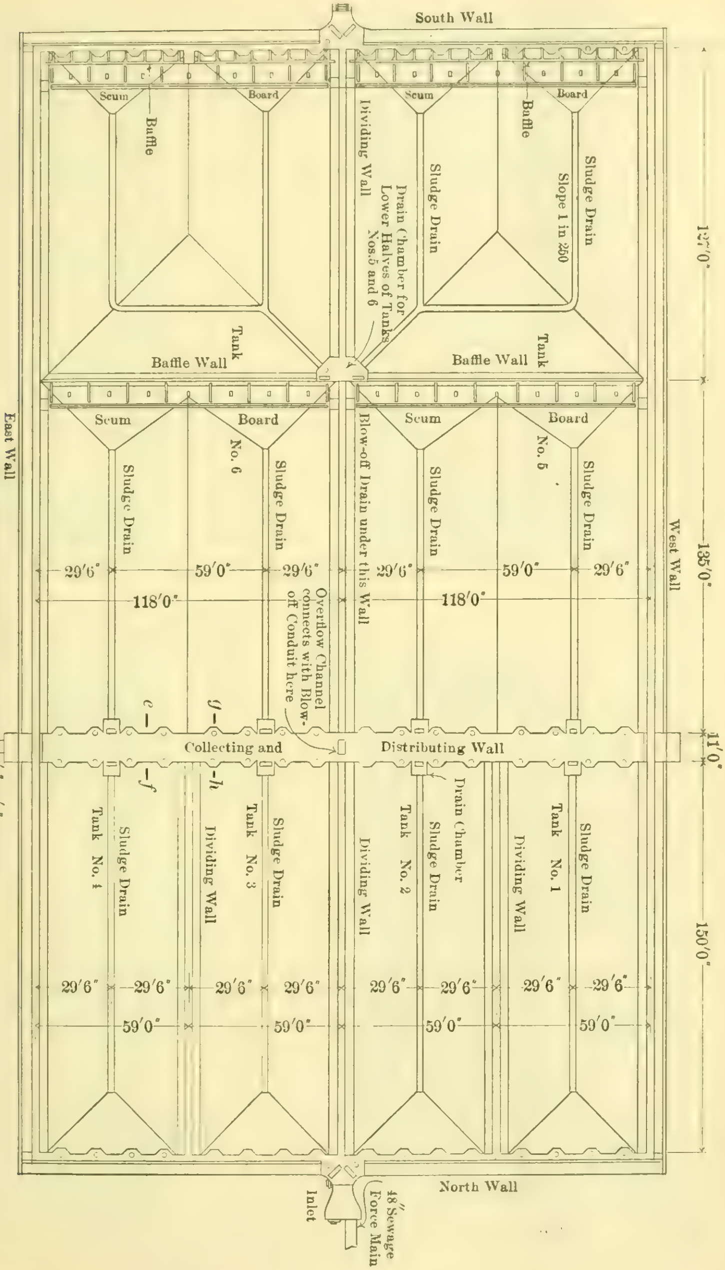
The chimney, which is of hollow radial brick construction, built by the Alphons Custodis Chimney Construction Company, is 5 ft. in diameter inside the fire-brick lining, and 130 ft. high above the boiler-room floor. The foundation of the chimney is carried on timber piles.

High water in the river is about 6 ft. above the engine-room floor, and in case of a break which would flood the pumping-station lot the station itself would be flooded. To care for this emergency, stop-plank grooves have been built in all the window and door openings, and a full set of stop-planks provided.

Screening Devices.—In the screen chambers for the East Side and West Side sanitary sewage, the screening devices consist of cages of steel-frame construction holding removable sets of screens, two cages to each chamber. In the front cages the screens are of ¾-in. round bars 1 in. apart, in the clear, and in the rear cages of ⅜-in. round bars ½ in. apart in the clear. On the floor above the chambers there is an iron superstructure from which the cages are hung, the cages being raised and lowered by simple reversing steam engines carried on the superstructure. In the screen chamber for the West Side storm-water,

PLATE XIX.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.





PLAN OF SEPTIC TANKS

Scale of Feet

0 20 40 60 80 100

Fig. 16.

which is used only when it is necessary to pump storm-water, there is a double set of vertical steel-frame screens of $\frac{3}{4}$-in. round bars 1 in. apart, in the clear, each section being provided with a catch-pan. The screens are raised and lowered by hand by a movable screen lifter hung from a traveling hoist and runway carried on the lower chord of one of the roof trusses. The material removed from the screens is disposed of on land.

Low-Lift Pumping Machinery.—For pumping the sewage and storm-water, five low-lift pumping units have been installed, space being left for a sixth unit. Each unit consists of a single-suction, horizontal, Worthington, volute pump, direct-connected to a vertical, cross-compound, Reeves engine. Three of the pumps have 20-in. suction and discharge pipes, and have a normal capacity of 11 000 000 gal. per 24 hours against a total suction and discharge head of 25 ft., and a maximum rated capacity of 14 000 000 gal. per 24 hours against a total head of 30 ft. The two smaller pumps have 12-in. suction and discharge pipes, and have a normal capacity of 4 000 000 gal. per 24 hours against a total suction and discharge head of 28 ft., and a maximum rated capacity of 5 000 000 gal. per 24 hours against a total head of 32 ft. Each of the five units can draw from any one of the three suction wells, as desired.

Boilers and Accessories.—In the boiler-room there are three 150-h.p., Babcock and Wilcox, horizontal, water-tube boilers carrying steam at 160 lb. pressure, space being left for a fourth boiler. In the basement of the engine-room there are two surface condensers and two vacuum pumps, and in the boiler-room a Green economizer, two boiler feed pumps, a heater, and a hot well.

Generators and Crane.—The building is lighted by two 10-kw., 250-volt, direct-current generators, each direct-connected to a vertical, simple engine. In the engine-room there is a 6-ton, Case, hand, traveling crane having a span of 41 ft. 4 in. and a travel the full length of the room.

Connections Between Main Sewage Pumping Station and Sewage Purification Works.

From the pumping station the sewage is pumped through a 48-in. cast-iron force main, 1.2 miles in length, to the sewage purification works. In the force main, just outside of the pumping station, is placed a 48-in. Venturi meter of special construction, similar to that

PLATE XX.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

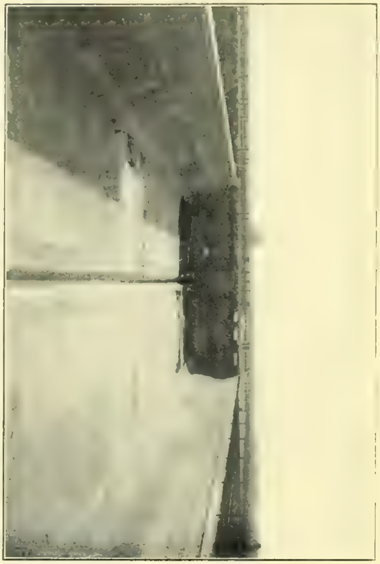


FIG. 1. VIEW OF PRIMARY SEPTIC TANK, LOOKING SOUTH.

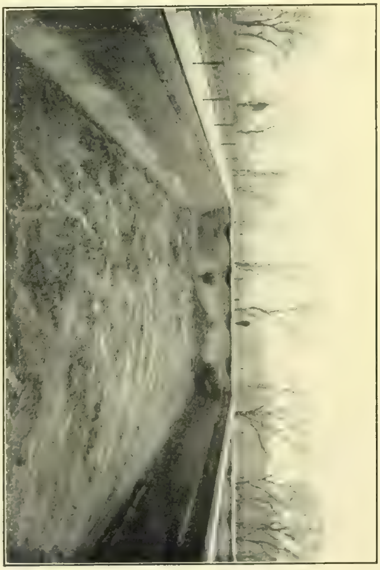


FIG. 2.—PRIMARY SEPTIC TANK, SHOWING SLUDGE JUST BEFORE CLEANING.

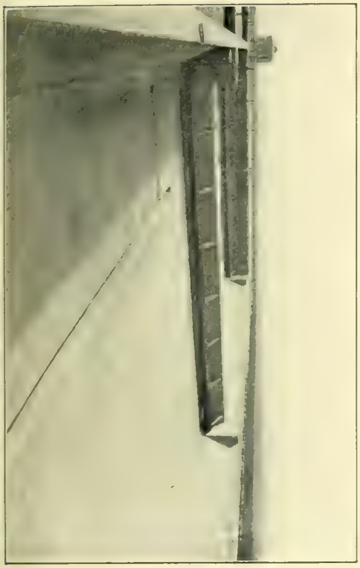


FIG. 3. VIEW OF SECONDARY SEPTIC TANK, LOOKING SOUTH.

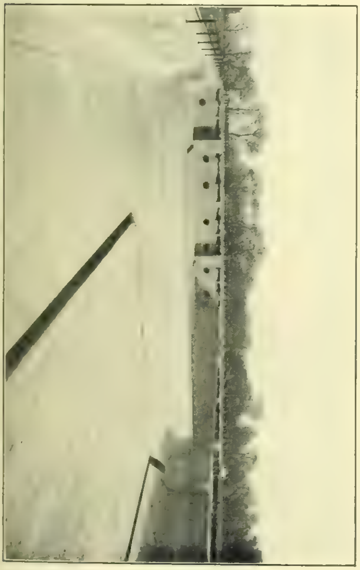


FIG. 4.—VIEW OF SECONDARY SEPTIC TANK, LOOKING NORTH.

used on the East Side sewage force main. The primary indicating and registering devices are in the engine-room.

A pole line from the pumping station to the purification works carries telephone wires and wires connecting with a secondary Venturi indicating and recording device in the gate-house at the purification works.

The Sewage Purification Works.

The sewage purification works are on the west bank of the Scioto River, the upper end being about 1.2 miles below the Main Sewage Pumping Station and about 3.5 miles south of the center of the city.

Type and Capacity.—As previously mentioned, the purification works comprise septic tanks, sprinkling filters, and settling basins, the present installation having a net normal capacity of 20 000 000 gal. per 24 hours. The arrangement of the works, however, is such that they may be extended to an ultimate capacity of 30 000 000 gal. per 24 hours, and the main conduits will carry 45 000 000 gal. per 24 hours. A general plan of the works is given on Plate XVII, and on Plate XVIII is shown more in detail the arrangement of the several structures and the layout of the various conduits and pipe lines.

It will probably be noticed by some that certain of the details, especially in the sprinkling filters, are somewhat different from what might be said to be current practice. In considering these details, however, it should be borne in mind that the Columbus sewage purification works were the first designed, and at present are the largest of their type now under operation, in the United States. When the works were designed, in 1905, the only precedent was English practice, where the sewage treated was much stronger than is that at Columbus, and, while excellent results had been obtained from the English works, many of the details adopted there would hardly have been, and still would not be, suitable for works subject to periods of severe winter weather, as in Columbus.

During the last four years much thought and study have been given to improving the details of construction and operation of sprinkling filters in the United States, and while, as previously mentioned, somewhat different details have been adopted in some of the more recent works, an examination of the designs seems to indicate that the details adopted and the experience obtained at Columbus have served as a basis from which to work.

Levee.—For protection from floods, the works are surrounded by a levee about 6 100 ft. long, its top being 6 ft. above the highest recorded water level in the river and from 10 to 15 ft. above the ground. The levee is 16 ft. wide on top, and has side slopes of 1½ horizontal to 1 vertical, the inner slope being dressed with loam and seeded. The railroad spur, which terminated on the levee east of Settling Basin No. 1, has been extended, since the purification works were finished, to connect with the garbage reduction works now under construction. A branch spur runs over to the north end of the septic tanks.

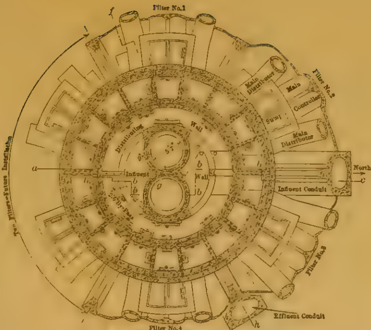
Septic Tanks.

There are six septic tanks, four so-called primary tanks and two secondary tanks; the details are shown on Plate XIX. The primary tanks are 56 ft. 6 in. by 150 ft., and the secondary tanks are 115 ft. 6 in. by 262 ft. The tanks, throughout, are of concrete, are not covered, and are approximately 12 ft. deep to the high-water line. Each primary tank has a capacity of 710 000 gal. and each secondary tank 2 590 000 gal. The four primary tanks have a total capacity of 2 840 000 gal. and the two secondary tanks a total of 5 180 000 gal., making a grand total of 8 020 000 gal.

Design.—The tanks were designed with the object of not only placing the outlets as far as possible from the inlets, but also of keeping the sludge as much as possible away from the outlets, this being accomplished by dividing the tanks longitudinally by tranverse walls into three sections. To meet varying conditions in the character of the sewage and in the quantity treated, the design was made very flexible, it being possible to use any combination of one or more primary tanks with either or both secondary tanks.

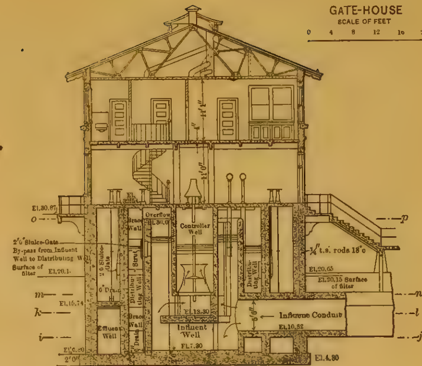
Operation.—As designed, the tanks were to be operated so that the rate of discharge from them would be practically constant during the 24 hours, the rate to be adjusted so that the total quantity drawn out would be as nearly as possible equal to the total quantity pumped in. As the rate of pumping varies from hour to hour, the surface level in the tanks, of course, fluctuates. With the mean hourly variation in the dry-weather flow, as determined during the experiments at the testing station, with the tanks all in service, and with a total flow of 20 000 000 gal. in 24 hours, the fluctuation would amount to about 3.1 ft., giving a minimum depth of about 8.9 ft. and a maximum depth of about 12 ft. in the tanks. On this basis, the average period of flow

SECTION ON *k-l*



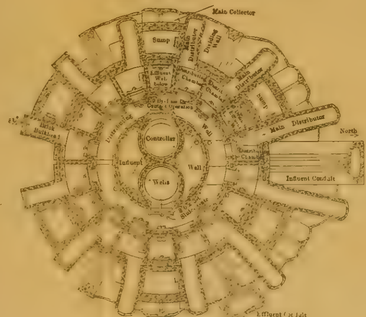
SECTION ON *o-p*

GATE-HOUSE

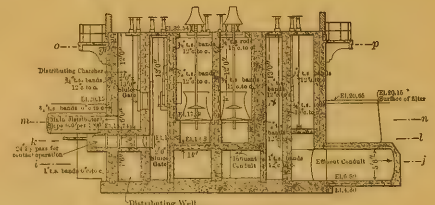


SECTION ON *a-b-c*

SECTION ON *i-j*



SECTION ON *m-n*



SECTION ON *f-g-h*

through the tanks would be about $8\frac{1}{2}$ hours. In the operation of the works, however, it has been found that satisfactory results have been obtained by maintaining a constant level in the tanks, and the tanks are now operated in this way.

North Wall.—The 48-in. sewage force main terminates in a bell-mouth at the center of the north wall. The north wall is of a combined construction, consisting of a 5 ft. 6-in. reinforced distributing conduit carrying a small retaining wall above. Sewage is admitted into each primary tank from the top of the conduit portion through four 2-ft. sluice-gates, the center of the gates being about 2 ft. 8 in. below the low-water line in the tanks. By means of grooves and movable stop-planks, the distributing conduit may be divided into two sections, so that either half may be drained for inspection while the other half is in service.

Collecting and Distributing Wall.—The primary tanks are separated from the secondary tanks by a heavy wall of cored construction, called the collecting and distributing wall. In the middle of this wall there is a 5-ft. collecting and distributing conduit, sewage from each primary tank flowing into the conduit through four 2-ft. sluice-gates, and passing out into each secondary tank through eight 2-ft. sluice-gates. In the bottom of the wall there is a 3 ft. 4-in. by 5-ft. blow-off conduit, and in the top there is an overflow channel which connects with the blow-off conduit below, sewage from the primary and secondary tanks flowing into the overflow channel over numerous weirs ranged along each side of the channel. These weirs would come into play only to prevent overflowing the outside walls of the tanks.

The sludge drains, in the primary tanks and in the upper section of each secondary tank, discharge, through small drain chambers, directly into the blow-off conduit in the collecting and distributing wall. In the lower section of each secondary tank the sludge drains discharge into a drain chamber located in the line of the dividing wall between the secondary tanks, and thence through a 2 by 3-ft. blow-off drain under the dividing wall into the blow-off conduit in the collecting and distributing wall. The arrangement of the sludge drains permits each primary tank and each section of each secondary tank to be drained independently.

Baffle Wall.—Each secondary tank is divided into two sections by a low baffle wall, to hold back the sludge at the bottom of the upper half of the tank, the top of the wall being about 1 ft. below low-water

level. On the up-stream side of the wall, and hinged to it, there is a floating scum-board, of cypress, to hold back any scum which might form in the upper half of the tank.

South Wall.—The south wall is similar in construction to the north wall, but the collecting conduit is not reinforced. The effluent from each secondary tank is drawn off through eight 2-ft. sluice-gates, a reinforced concrete baffle and a floating scum-board holding back the sludge and any scum which might possibly form.

Dividing Walls and Floors.—All the dividing walls have a gravity section. The east and west outside walls have the same section as the dividing walls, as they will become dividing walls when the tanks are extended. The floors are all 6 in. in thickness, and no special attempt was made to make them water-tight, as it was thought that the joints between the floor-blocks would rapidly silt up and become tight.

Blow-off.—From the east end of the collecting and distributing wall a 3 ft. 4-in. by 5-ft. blow-off conduit extends to a blow-off gate-chamber in the levee on the east side of the works, from which two blow-offs run to the river, the larger one, 4 ft. in diameter, having its outlet at the edge of the river. The smaller one, 16 in. in diameter, extends out farther, and has three outlets in the center of and at the bottom of the river. All the outlets are protected by flap-gates, and in the gate-chamber each blow-off is fitted with a sluice-gate. The 4-ft. blow-off was provided to care for a large volume of sewage which might pass over the overflow weirs in the collecting and distributing wall, and the 16-in. blow-off is for use when the tanks are drained. For the present, the sludge is disposed of in the river when the river rises and the dilution is sufficiently great, but the city has acquired a large tract of land, adjoining the works, and remote from buildings, which can be used for sludge disposal should this be found desirable or necessary at a later date.

Gate-House.

From the center of the south wall of the septic tanks the sewage flows through a so-called influent conduit to the gate-house. This conduit, 5 ft. 6 in. in diameter, of reinforced concrete, is located under the dividing wall between Filters Nos. 2 and 3. The flow from the septic tanks and to and from the sprinkling filters is controlled at the gate-house, the details of which are shown on Plate XXI.

Substructure.—The substructure of the gate-house is of concrete,

PLATE XXII.
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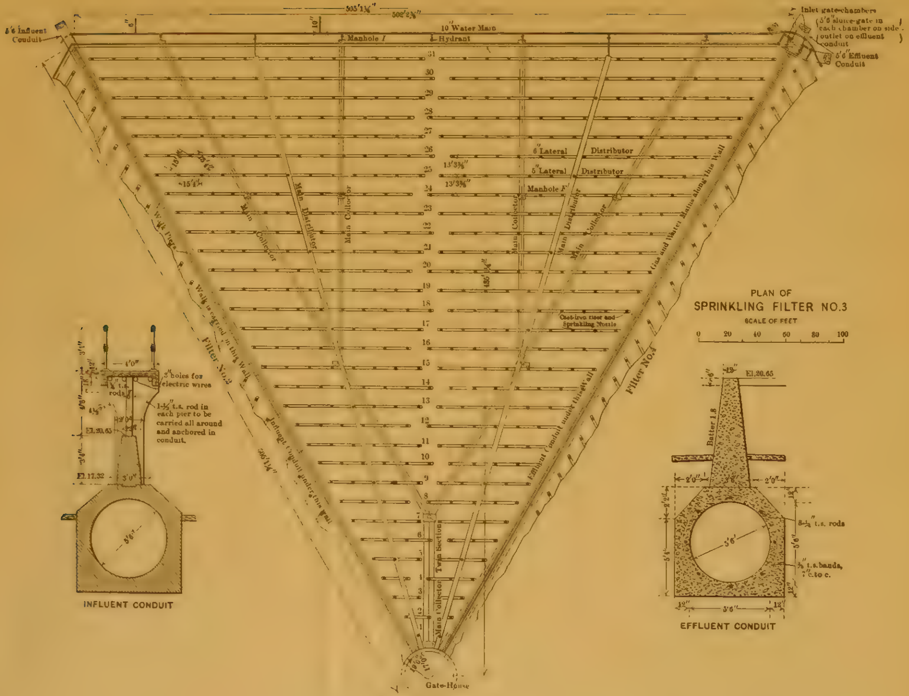
JANUARY, 1910.
[redacted] ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



heavily reinforced, and its outside diameter is 38 ft. Sewage is first admitted from the influent conduit into an influent well, 15 ft. in diameter and 25 ft. 3 in. deep, located in the center of the substructure. The influent well encloses two controller wells, approximately elliptical in plan, each 6 ft. 6 in. wide and 7 ft. long, through which the sewage flows out into an annular distributing well, 3 ft. in width, enclosing the influent well. From the distributing well the sewage passes into a series of distributing chambers connecting with the distribution systems in the filters. These distributing chambers are built in the upper portion of the outer annular well of the substructure, the lower portion being termed the effluent well, into which the effluent from the filters flows.

Each controller well contains a specially designed controller, adjustable from a minimum capacity of 10 000 000 gal. to a maximum capacity of 22 500 000 gal. per 24 hours, and operating under a minimum loss of head of about 0.75 ft.

These controllers were installed to care for the fluctuating head in the septic tanks, but, on account of the change in the method of operating these tanks, with a constant level, the controllers are not at present in use. A description of them and their action, however, may be of interest.

The controller consists of a flaring tube in which a pressure disk, attached to a vertical stem, moves up and down. The rate of flow through the controller, therefore, is dependent on the annular area between the pressure disk and the flaring tube, and on the difference in head between the two sides of the disk. The upper end of the vertical stem is shouldered, and picks up successively, as it rises, a series of weights until the difference in head on the pressure disk is balanced. With a given position of the vertical stem relative to the nest of weights above, the controller maintains automatically a practically constant rate of flow, the pressure disk and stem rising as the level in the septic tanks rises, and falling as the level in the tanks falls. The rate of flow through the controller is varied by adjusting the position of the stem relative to the nest of weights.

With the quantity of sewage at present treated, only one controller ordinarily would be in service, it being set to discharge in 24 hours, as nearly as possible, the estimated quantity which would be pumped into the septic tanks during the 24 hours, but, in case the controller should be set too low and the septic tanks should fill up to the high-

water line, and the rate of flow into the tanks should then continue in excess of the quantity discharged by the controller, this excess would pass over an overflow on the influent well into the distributing well and out to the sprinkling filters, by building up a greater head on the distribution systems. This overflow is set at a lower elevation than the overflows in the septic tanks, and would come into play before sewage would pass over the overflows in the tanks and out to the river.

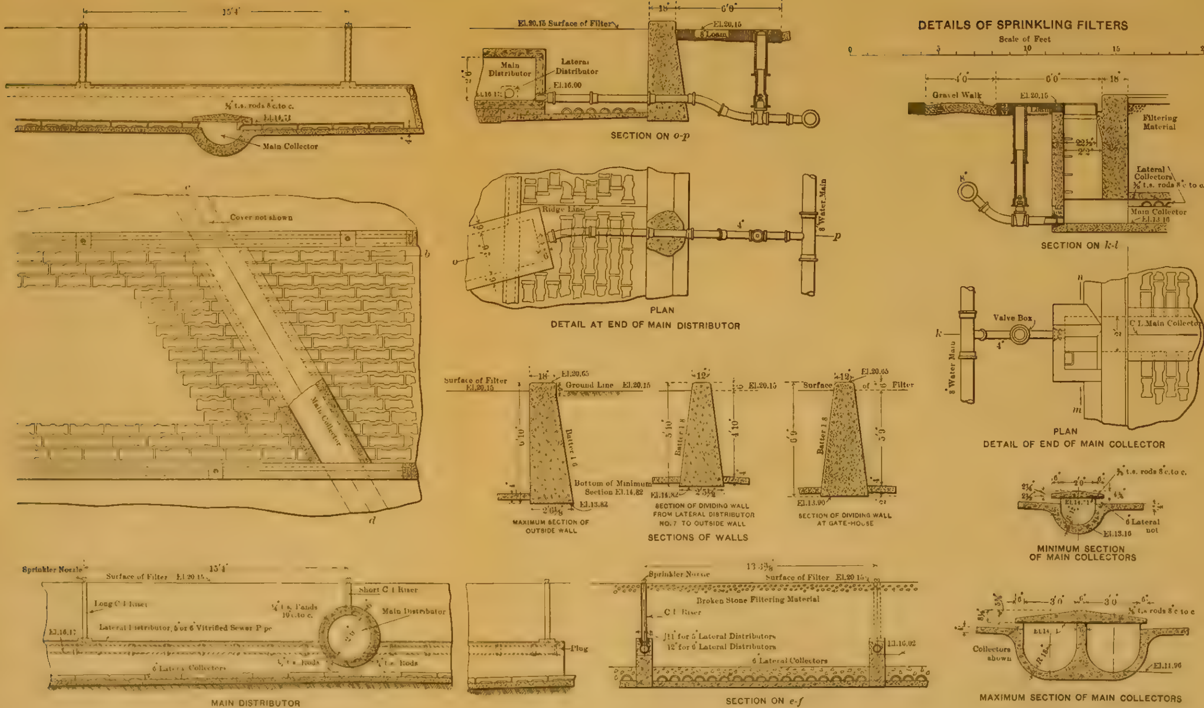
In case of long-continued and excessively cold weather, provision has been made to operate the sprinkling filters as contact filters, if so desired. Under such conditions, the distribution systems would be shut off and drained, and the filters would be filled from below through by-pass gates and pipes leading from the distributing well, as may be seen by referring to Plate XXI. The main effluent gate of each filter, of course, would be closed while the filter was filling, and opened slowly during the period of draining. It is also possible to by-pass the filters entirely by shutting the outlet gates from the distributing well and opening the gates connecting the distributing well directly with the effluent well.

Superstructure.—The superstructure of the gate-house is also circular in plan, and is two stories in height. In the lower story are located the various stands for operating the sluice-gates and controllers, a chart recorder for showing the level in the septic tanks, an indicator for showing the head on the sprinkling nozzles in the filters, and a secondary indicator and chart recorder for giving the rate of flow through the 48-in. Venturi meter at the main sewage pumping station and thus through the force main into the septic tanks. The second story is divided into an office, chemical and bacteriological laboratories, a locker-room, and a lavatory containing a shower bath and sanitary conveniences. The character of the construction of the superstructure is similar to that of the superstructure of the main building at the water purification works, previously described.

Sprinkling Filters.

There are four sprinkling filters, radiating from the gate-house, each being an equilateral triangle in plan, 505 ft. 1¼ in. on a side. With the construction of two additional filters, space for which has been reserved, they will form a hexagon with the gate-house at the center. Each filter has a net area of 2½ acres, making a total of 10

DETAILS OF SPRINKLING FILTERS



acres for all four, but, as the distribution system in each filter has been designed so that one-half of the filter can be operated independently of the other half, the present installation, from the standpoint of operation, may be considered as consisting of eight filters of 1¼ acres each.

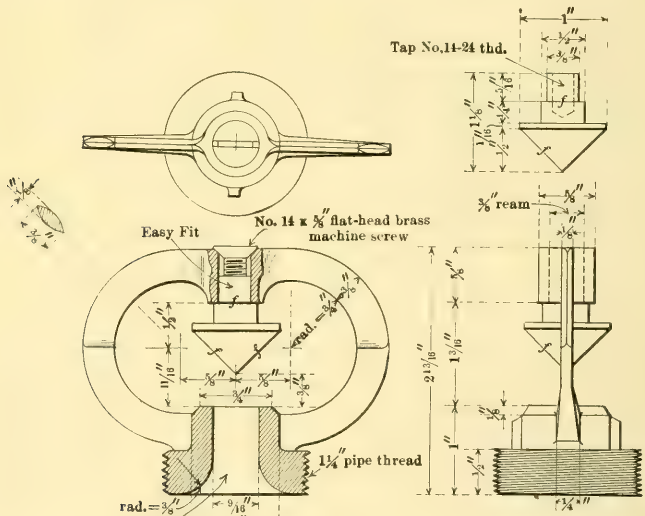
The filters are designed to yield normally 2 000 000 gal. per acre per 24 hours, resting one-half of the time, requiring therefore a rate of 4 000 000 gal. per acre per 24 hours when in service. It is possible, however, to operate them at somewhat higher rates. The details of the filters are shown on Plates XXII and XXIII.

Walls.—The outside and dividing walls were of concrete, and were designed simply as light retaining walls and not to resist water pressure on one side with no filtering material on the other. To provide access to the gate-house, so that it can be reached when the two additional filters are constructed, without having to walk across the surface of the filters, an elevated reinforced concrete walk has been built above and is supported on the dividing wall between Filters Nos. 2 and 3.

Distribution System.—In order to provide protection from the frost, the distribution system is built below the surface of the filters, and consists of main distributors, lateral distributors, vertical risers, and sprinkling nozzles. The main distributors, of which there are two in each filter, are of reinforced concrete, 2 ft. 6 in. in diameter, and radiate from the gate-house. Connecting with the main distributors are the lateral distributors, which consist of lines of 5-in. and 6-in. vitrified sewer pipe supported by and bedded in the upper part of small concrete walls. From outlets in the top of the main distributor, and from sewer pipe branches set vertically in the lateral distributors, 3-in. cast-iron risers extend to the surface of the filters, the sprinkling nozzles being screwed into the upper ends of the risers. The joint at the base of each riser is made with lead caulked into the vitrified pipe socket. The distribution system in each filter is designed so that when shut off it can be drained out back to the gatehouse.

The sprinkling nozzles are 15 ft. 4 in. from center to center, the arrangement being such that the straight lines connecting three adjacent nozzles form the sides of an equilateral triangle. The nozzle, Fig. 17, is of brass, and consists of a single orifice, $\frac{9}{16}$ in. in diameter, with rounded edges, above which, held by two thin arms, there is an inverted 90° cone, the axis of the cone coinciding with the axis of the

orifice. The jet, on leaving the orifice, impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops. At the points where the sheet strikes the arms, the latter are ground down to sharp edges on each side in order to permit the sheet to heal up after passing them. When the filters are operating at a rate of 4 000 000 gal. per acre per 24 hours, each nozzle will discharge approximately 13.1 gal. per min. under a head of 5 ft. available at the nozzle. There are 2 108 nozzles in the 10 acres of filter surface, about 211 nozzles per acre, the area tributary to each nozzle being 206.6 sq. ft.



SPRINKLING NOZZLE

Scale of Inches

0 1 2

FIG. 17.

The experimental investigation at the testing station demonstrated that satisfactory results could be obtained when operating nozzles under a constant head, and the works were designed with this in view, but it has since been found that better results are obtained if the head is allowed to fluctuate, and the filters are now operated in that manner, the head on the nozzles being varied from hour to hour by hand, by throttling the sluice-gates in the gate-chamber. Modifications in the gate-house are being contemplated whereby the head will be made to fluctuate automatically.

Fig. 1.—View of Sprinkling Filter No. 1. Looking Toward Site of Gate-House.

Fig. 2.—Sprinkling Filters: Main and Lateral Distributors.

Fig. 3.—Sprinkling Filters: Main Distributors and Main Collectors in Foreground.

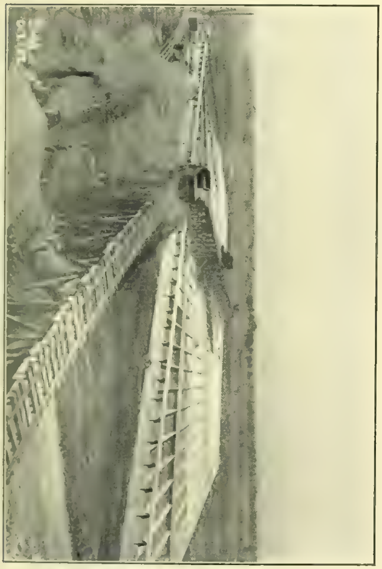


Fig. 4.—View of Sprinkling Filters Nos. 1 and 2 During Construction.

Filtering Material.—The filtering material consists of broken stone having a total average depth of about 5 ft. 4 in., the lower 10 in. being from 3 to 4 in. in size. In Filters Nos. 1 and 2 the material above the lower course has a nominal size of from 1½ to 3 in. The material was sampled carefully from time to time, and mechanical analyses were made from which it was found that the effective size was 1.4 in. and the uniformity coefficient 1.4, and that the average size of the stone was 1.7 in., that being the diameter of a sphere of equal volume. In Filters Nos. 3 and 4 the material has a nominal size of from 1 to 3 in., an effective size of 1.1 in., a uniformity coefficient of 1.6 in. and an average size of 1.5 in. The material is all limestone, obtained partly from quarries near Columbus and partly from Marion, Ohio, and was screened at the quarries to remove the dust and fine particles and to obtain material of the right size.

Collection System.—For removing the effluent from the filters, a very free-draining bottom has been provided, consisting of lateral collectors discharging directly into main collectors. The lateral collectors are 6-in. vitrified channel pipe, with the sockets left off, notched on both edges, and laid in parallel lines, a space of ¾ in. being left between each two pipes longitudinally. The floors of the filters, which slope to the main collectors, are of concrete, 4 in. thick, the edges of the lateral collectors being bedded on the floor before the concrete had obtained its initial set.

The main collectors, which are of concrete, below the level of the floor of the filters, have a semicircular invert with vertical sides above and gradually increase in section toward the gate-house. The flow line is below the level of the filter floor, so that the ends of the lateral collectors will not be submerged. The main collectors in each filter discharge into a common sump and thence into the effluent well in the gate-house, the flow line in the sump being below the level of the invert of the lower end of the main collectors, so that when a main collector is not in use it will drain out completely. Manholes furnish access to the main collectors, for inspection.

Settling Basins and Outfall.

From the substructure of the gate-house the effluent from the sprinkling filters flows through a so-called effluent conduit, to an inlet gate-chamber, then through the gate-chamber and through two inlet

conduits to the settling basins. The effluent conduit is of reinforced concrete, is 5 ft. 6 in. in diameter, and is located under the dividing wall between Filters Nos. 3 and 4.

Inlet Gate-Chamber and Conduits.—The inlet gate-chamber is of concrete, and is all below the surface of the ground; that part in connection with the effluent conduit is heavily reinforced. The flow from the effluent conduit is controlled by two 5½-ft. sluice-gates. The inlet conduits are also 5½ ft. in diameter, and are of concrete but are not reinforced. The sewage is admitted from the inlet conduit into each settling basin through fifteen 21-in. vitrified sewer pipe inlets terminating in a low wall.

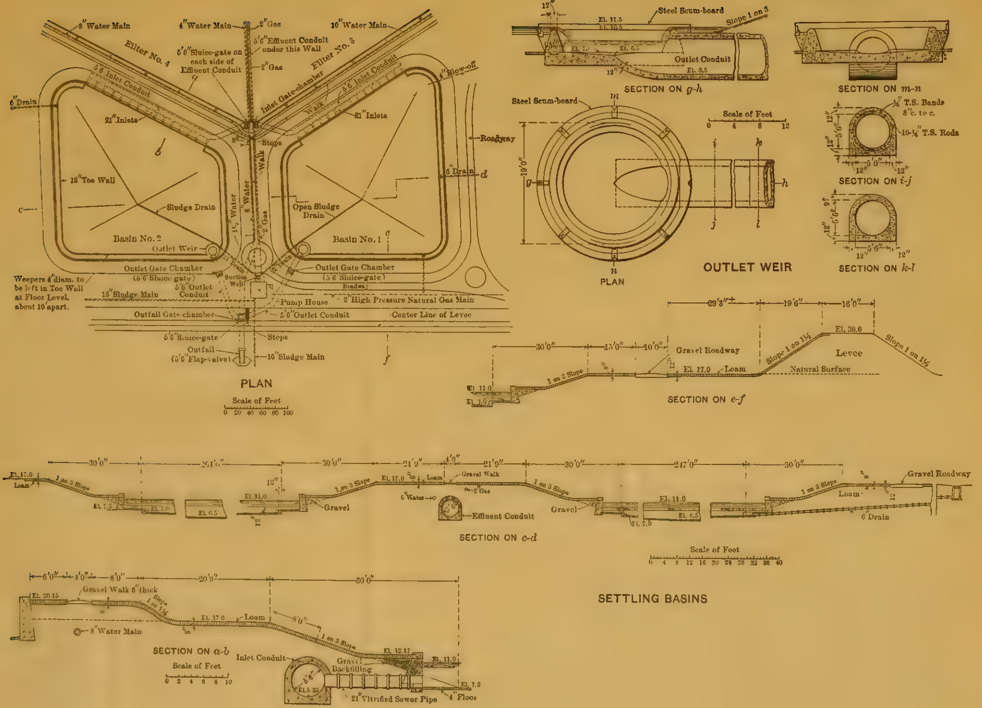
Settling Basins.—The effluent from the sprinkling filters is not perfectly clear, and, to remove the heavier particles in suspension, it is at times allowed to flow through one or both settling basins before passing out to the river. Each settling basin has a capacity of 2 000 000 gal., and, with one basin in use, and when handling 20 000 000 gal. of sewage per 24 hours, the average period of flow through the basin would be a little less than 2½ hours. The basins are from 4 to 4½ ft. deep, the water line being at Elevation 11.0, about 5 ft. above mean low water in the river.

The basins are not covered, and are all in excavation. As originally built, the side slopes were 3 horizontal to 1 vertical, and were not paved or otherwise protected, except that above the water line the slope was grassed; the berm at the foot terminated at a low toe-wall, 12 in. high. On account of lack of funds, when the works were designed, it was decided to omit retaining walls around the sides of the basins, but, funds having become available since the works were completed, the retaining walls were built during the summer of 1909. The floors are of concrete, 4 in. thick, and simply provide a suitable surface for the flushing out of sludge. No attempt has been, or will be, made to exclude ground-water, on the contrary, weep-holes, 4 in. in diameter and 10 ft. apart, have been left in the toe-wall, so as to admit ground-water and prevent an upward water pressure on the floor.

The effluent from each settling basin flows off in a thin sheet over a circular outlet weir, 19 ft. in diameter, floating matter being held back by an easily removable sheet-steel scum-board.

The details of the settling basins are shown on Plate XXV.

PLATE XXV.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



Outlet Conduits and Outfall.—From the outlet weirs the effluent from the settling basins flows through the outlet conduits to the outfall gate-chamber and thence to the outfall on the bank of the river. The outlet conduits are 5½ ft. in diameter, and are of reinforced concrete. On each of these conduits there is an outlet gate-chamber containing a 5½-ft. sluice-gate, so that either or both basins may be shut off when desired. At the outfall a 5½-ft. flap-gate has been provided, and, in the outfall gate-chamber, there is a sluice-gate of the same size, for use in case the flap-gate should fail to seat tightly during high water in the river, when it might be desired to shut down the works. From the inlet gate-chamber the effluent conduit is extended to the outfall gate-chamber, and serves as a by-pass around the settling basins, by closing the gates in the inlet and outlet gate-chambers.

Pump-House and Connections.

For the present the sludge accumulating in the settling basins is disposed of by discharging it into the river when the river rises and the dilution is great, the same as the sludge from the septic tanks. At such times the settling basins will not drain to the river, but must be pumped out, and, for this purpose, a small suction well and pump-house, the details of which are shown on Plate XXVII, have been built at the east end of the embankment dividing the two settling basins.

Suction Well.—The suction well, located just outside the pump-house, is a small concrete structure, 5 ft. 6 in. in diameter and 15 ft. 7 in. deep, and into this the sludge drain in each settling basin discharges through a 21-in. pipe. From the well two 12-in. suction pipes extend into the substructure of the pump-house.

Pumping Machinery.—The pumping machinery consists of a horizontal, Worthington, volute pump, with 12-in. suction and 10-in. discharge nozzles, driven, through a silent-running high-speed chain, by a 50-b.h.p., vertical, enclosed, three-cylinder, Nash, gas engine, running on natural gas having a thermal value of about 1 000 B. t. u. per cu. ft. The unit has a capacity of 3 000 gal. per min. against a head of 14 ft., and 2 000 gal. per min. against a head of 26 ft., when pumping a mixture weighing 75 lb. per cu. ft. For the present, only one pumping unit has been installed, but space in the building has been provided so that the equipment may be duplicated.

Building.—The superstructure of the building is 23 ft. 6 in. square inside, is one story high, and is of the same character of construction

as the superstructure of the gate-house. The substructure is of concrete.

Sludge Mains.—Outside of the building the discharge pipe from the pump branches into two sludge mains, one 16 in. and the other 15 in. in diameter. The 16-in. main extends out into the river, with outlets below the surface, being a duplicate of the blow-off used for draining sludge from the septic tanks. The 15-in. main terminates at present at the site of the garbage reduction works. When the sewage purification works were designed, it was not expected that the garbage disposal works would be located adjacent to the sewage purification works, and the levee was built in a position other than that shown on Plate XVII, with the 15-in. main terminating outside of the levee. This main was laid so that, if disposal of the sludge from the settling basin on land was found desirable, an outlet would be provided. In the fall of 1908 a portion of the levee in the southeast corner of the works was moved so as to provide a site for the reduction works, but the sludge main will not be extended until after the reduction works are built; its final location will then be determined.

Miscellaneous.

Water Main.—In the main and lateral distributors and in the main collectors of the filters, in order to keep the friction losses low, it was necessary to use depositing velocities. To provide means for flushing these out in case of deposition, a water main has been laid with a branch connecting directly with the outer end of each main distributor and each main collector. To flush out the lateral distributors, the nozzle in the riser at the outer end of each distributor would be removed and a hose connection made with one of the hydrants placed along the outside walls of the filters. Hydrants have also been placed adjacent to the septic tanks and settling basins, so that an ample supply of water under pressure may at all times be obtained for flushing purposes.

Loss of Head.—The total loss of head through the works, from high-water line in the primary septic tanks to mean low water in the river, is 25.34 ft., and, without giving all the individual losses through gates, conduits, etc., may be summarized as given in Table 13. It should be stated that the losses are computed on the basis of the works handling a maximum quantity of 45 000 000 gal. per 24 hours.

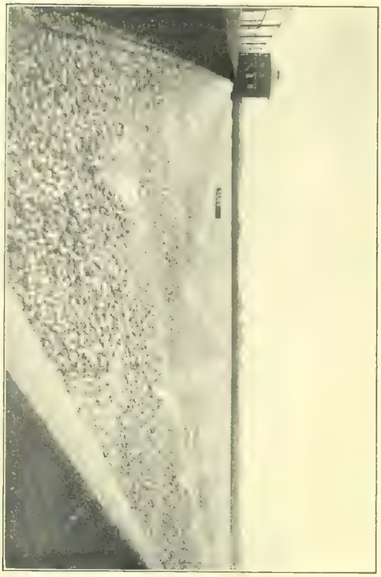


FIG. 1. VIEW OF SPRINKLING FILTER NO. 2.

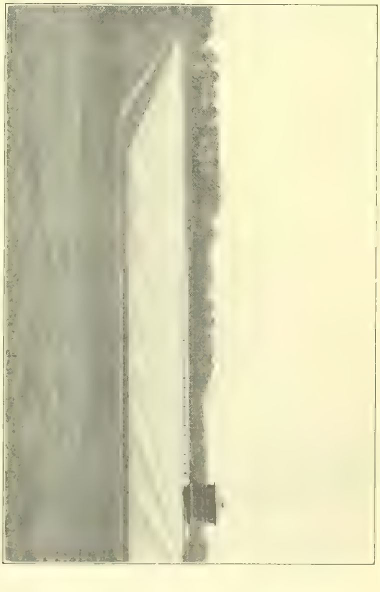


FIG. 2.—VIEW OF SPRINKLING FILTERS NOS. 1 AND 2.

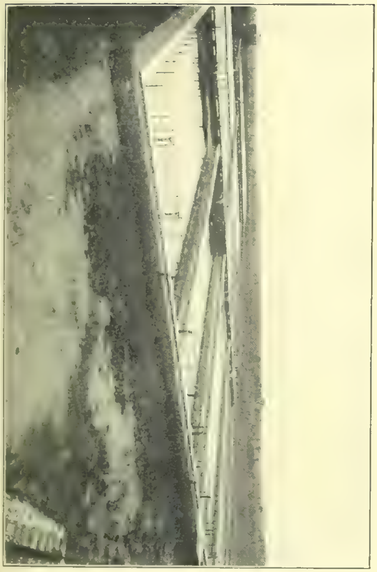


FIG. 3. VIEW OF SEPTIC TANKS, FROM NORTH END.

TABLE 13.—Loss of Head Through Works.

Location.	Elevation, in feet above city datum.	Loss of head, in feet.
High-water line, primary septic tanks	31.34	....
Low-water line, primary septic tanks	28.24	3.10
Hydraulic grade at sprinkling nozzles	25.15	3.09
Surface of filter	20.15	5.00
Hydraulic grade, lower end of main collector	13.77	6.38
Hydraulic grade, effluent well in gate-house	11.96	1.81
Water line, settling basins	11.00	0.96
Mean low water in river	6.00	5.00
Total	....	25.34

Operation During Freshets.—With a 5-ft. rise in the river, the settling basins would be shut off, but the filters could still be operated under normal conditions. With a total rise of 7 ft. in the river the filters would cease to be free-draining at the bottom, and would probably be shut off. It would be possible, however, still to operate the filters with a greater rise than 7 ft. in the river by allowing them to fill up with sewage sprayed on from the sprinkling nozzles until the filters were full up to the surface. Whether or not this method of operation would be satisfactory can only be determined by trial. At the best, however, operation at such times would require the most careful supervision, as the river may easily rise at the rate of 0.75 ft. per hour, and, unless the filters were shut off at the proper time, the outside walls would be overflowed. Again, if, for any reason, the flap-gate at the main outfall should become deranged at such a time, the river, which is highly turbid during freshets, might back up into the filters and deposit a large amount of mud, a result which would be simply disastrous, as in all probability the stone would have to be removed from the filters and washed, and the filters themselves would have to be cleaned and washed out. Assuming, however, that the filters are shut off with a 7-ft. rise in the river, the septic tanks can still be operated, even up to maximum high water in the river, the effluent from the tanks flowing to the gate-house, through the by-pass between the influent and effluent wells, and then out through the effluent conduit directly to the river.

Concrete.

In the construction of the sewage purification works, concrete, both plain and reinforced, was used extensively. The relative volumes of cement, sand, and ballast in the several classes of work were as follows:

1 : 2 : 4.—Water-tables, belt-courses, window-sills, lintels, etc.; substructure of gate-house (except foundation floor), and walk over influent conduit wall; reinforced floors, columns, stairways, and steps.

1 : 2½ : 5½.—Sprinkling filters, settling basins, collecting and distributing, and north and south walls of septic tanks; conduits and blow-offs, foundations, and miscellaneous small structures.

1 : 3 : 7.—East and west outside walls, baffle walls, and dividing walls of septic tanks (except collecting and distributing wall).

The specifications for the concrete were similar to those for the water purification works, and the method of mixing and placing the material was practically the same. The expansion joints, which were built where necessary, consisted, however, only of a tongue and groove in the concrete, no steel plates being used. The tongues and the grooves were well reinforced, both vertically and horizontally, with twisted steel rods.

Cost of Work.

In Table 14 the cost of the work in detail is given, and in Table 15 is given the unit cost of the main features of the work. As was the case with the cost of the water-works improvements, and for the same reason, no attempt has been made to distribute the cost of engineering over the several parts of the work.

Contractors and Progress of Work.

The first bond issue was authorized in November, 1903, and the preparation of the first drawings and specifications began early in 1904. The first work placed under contract was the testing station, in May, 1904. Additional contracts were let during 1904 and 1905, and in November, 1905, the purification works were placed under contract. The work was all practically completed by the fall of 1908, although the last contract, for the concrete walls around the settling basins, at the purification works, was not let until April, 1909. Sewage was first pumped regularly to the purification works on November 28th, 1908.

The principal contracts for the work were:

Levees and railroad spur.........The T. A. Gillespie Company and D. E. Sullivan and Son.

Bridge ....Cooke and Grant, and Houston and Cleveland.

PLATE XXVII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
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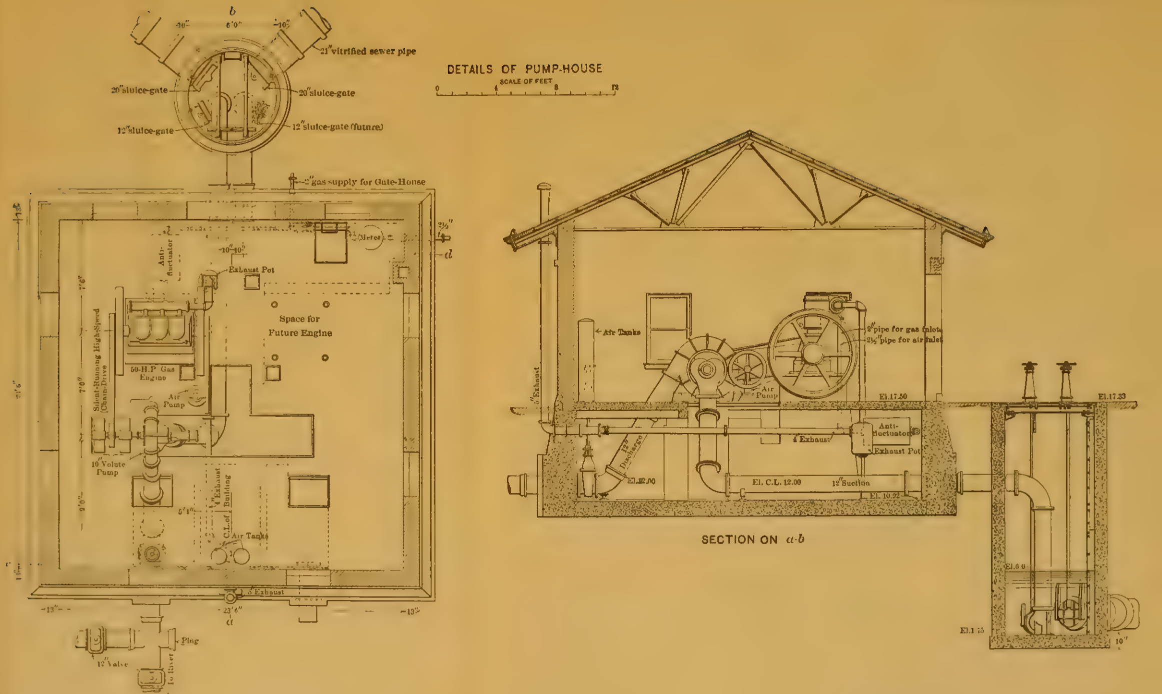
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



Sewers .... Westwater and Casey, and C. T. McCracken and Company.
Sewage force mains............ Westwater and Casey, and The York Construction Company.
Pumping stations............... Westwater and Casey, and D. W. McGrath.
Pumping machinery........... Woollen and Callon, and Columbus Machine Company.
Sewage screens and sluice-gates. . Coffin Valve Company.
Sewage purification works........ Sullivan, Murphy and Miles, and D. E. Sullivan and Son.

Operation.

The daily records of the results of operation of the sewage purification works for the eight months, January to August, 1909, inclusive, are presented in Table 16. As it is through the courtesy of the Engineer and Chief Chemist of the works that the writer is enabled to present these results, he will not enter into a detailed discussion of them, but hopes that such a discussion will be presented by these officials.

In order that the efficiency of the works may be judged, there is presented in Table 17 the final averages of the results obtained in the experimental investigation with Test Filter *C*, this filter having given the best results of those experimented with at the testing station.

From an examination of the data in these two tables it will be noted that during the earlier part of the period of operation the results secured at the purification works were much below normal, due largely, among other factors, to the unusually strong sewage, and especially to the fact that the filters were started at the most unfavorable time of the year, that is, just at the beginning of cold weather, and therefore had been afforded no opportunity to ripen.

With the advent of warmer weather, however, a steady improvement in the character of the results began, and from an examination of the later results secured at the works it will be seen that they compare very favorably with the results obtained with Test Filter *C*, thus demonstrating that the works serve, in a satisfactory manner, the purpose for which they were designed. The writer has but one comment to add, and that is, from such information as he can secure, it would

TABLE 14.—Cost of Sewage Improvements.

East Side Sewage Pumping Station and Force Main.				
Land .... 2 acres			$3 500	
Roads, Walks, Grading, and Drainage of Grounds.				
Roads, walks and grading		$1 810		
Drainage of grounds		160	1 970	
Sewer, Gas, Water, and Electric Connections.				
Sewer connections		1 260		
Gas supply connection		170		
Water supply connection		80		
Electric connections		120	1 630	
Pumping Station.				
Building.				
Substructure	$6 330			
Superstructure .... 25 700 cu. ft.	5 480	11 810		
Machinery and Equipment.				
Screening equipment	540			
Centrifugal pumps and gas engines 2	9 480			
Piping and appurtenances for engines	1 050			
Suction and discharge piping	1 950			
Miscellaneous equipment	40	13 060	24 870	
20-in. Sewage Force Main.				
20-in. Venturi meter		1 530		
20-in. force main .... 8 120 lin. ft.		37 030		
Manholes		1 930		
20-in. blow-off and manhole at pumping station		920	41 410	$73 380
Levees and Railroad Spur to Main Sewage Pumping Station and Sewage Purification Works.				
Land .... 65 acres			15 580	
Levees .... 9 780 lin. ft.				
From Hocking Valley Railway to bridge .... 1 270 lin. ft.		8 880		
From bridge to pumping station lot .... 1 800 lin. ft.		10 830		
On river side of pumping station lot .... 860 lin. ft.		12 590		
From pumping station lot to purification works .... 5 850 lin. ft.				
Levee	23 880			
Culverts .... 458 lin. ft.	4 380	28 260	60 560	
Bridge.				
Substructure.				
Earthwork	1 740			
Timber piling	2 250			
Concrete piers and abutments	10 490	14 480		
Superstructure.				
Steelwork	42 070			
Timber bridge floor .... 460 lin. ft.	930	43 000	57 480	
Railroad Track .... 9 760 lin. ft.				
From Hocking Valley Railway to bridge .... 1 250 lin. ft.		2 990		
On bridge .... 460 lin. ft.		430		
From bridge to pumping station .... 1 830 lin. ft.		3 860		
At river side of pumping station. 620 lin. ft.		1 300		
From pumping station to purification works .... 5 600 lin. ft.		11 810	20 390	154 010
Carried forward				$227 390

TABLE 14.—(*Continued.*)

Brought forward				$227 390
ADDITIONAL LEVEE CONSTRUCTION.				
Land .....26 acres			$8 760	
Levee north of bridge .....2 450 lin. ft.			10 260	
Levee south of purification works			820	19 840
GRAVEL ROAD FROM MAIN SEWAGE PUMPING STATION TO SEWAGE PURIFICATION WORKS				1 620
RECONSTRUCTION OF SEWERS IN WEST SIDE DISTRICT				16 090
ENLARGING AND REGRADING RENICK RUN DITCH, 4 020 lin. ft.				7 080
WATER AND GAS MAIN EXTENSIONS.				
10-in. Water Main.				
From High Street to pumping station, 4 550 lin. ft.		$8 080		
From pumping station to purification works .....6 400 lin. ft.		8 870	16 950	
2-in. high-pressure gas main from Stimmel Road to purification works .....8 760 lin. ft			1 740	18 690
SEWER EXTENSIONS TO MAIN SEWAGE PUMPING STATION LOT.				
48-in. Intercepting Sewer.				
Land .....1 acre		140		
Relief outlet		1 570		
Extension of 48-in. sewer .....540 lin. ft		10 370	12 080	
West Side Sewers.				
Land .....2 acres		1 500		
West Side sanitary and Renick Run storm-water sewers		115 490	116 990	129 070
WORK AT MAIN SEWAGE PUMPING STATION LOT.				
Levee around lot .....1 230 lin. ft.			7 870	
Roads, Walks, Grading, and Drainage of Grounds.				
Roads, walks, and grading		2 350		
Drainage of grounds		950	3 300	
Railroad siding north and south of coal pocket, 560 lin. ft.			1 230	
Connection to water main			180	
Sewers, connections and outlets to river			40 480	
Force Main Connections.				
To 48-in. sewage force main		1 150		
To 48-in. storm-water force main		1 390	2 540	
48-in. storm-water force main to river, 270 lin. ft.			2 960	58 560
MAIN SEWAGE PUMPING STATION.				
Building .....358 800 cu. ft.				
Substructure .....110 200 cu. ft.		25 710		
Superstructure .....248 600 cu. ft.		29 010	54 720	
Chimney.				
Substructure .....13 ft. deep		1 400		
Superstructure .....5 ft. diam., 130 ft. high		3 300	4 700	
Machinery and Equipment.				
Screening equipment and press		17 970		
Engine-driven centrifugal pumps, large units 3		12 670		
Engine-driven centrifugal pumps, small units 2		6 030		
Electric generating units and switch-board .2		2 640		
Boilers and accessories .....450-h.p.		7 980		
Steel boiler flue		1 010		
Suction and discharge piping		8 610		
Steam appurtenances and piping		11 440		
Miscellaneous equipment		770		
Hand traveling crane		3 300	72 420	131 840
Carried forward				$610 180

TABLE 14.—(*Continued.*)

Brought forward				$610 180
48-in. Sewage Force Main.				
48-in. Venturi meter and vault			$4 450	
48-in. force main ....6 370 lin. ft.			76 280	
16-in. blow-off			320	81 050
Pole Line from Pumping Station to Purification Works				1 100
Land for Sewage Purification Works..262 acres				49 500
Sewage Purification Works.				
Levee (earthwork in excess of that obtained from excavations for structures)..6 100 lin. ft.			10 330	
Railroad spurs on levees.... 1 330 lin. ft.			2 500	
Roads, walks, grading, and draniage of grounds			3 590	
3-ft. culvert at north end of works....310 lin. ft.			2 700	
Gas mains and connections			490	
10-in. water main and connections			6 020	
Septic Tanks....8 020 000 gal.				
Earthwork		$3 040		
Concrete and brick masonry		46 740		
Steel reinforcement		1 330		
Sluice-gates		12 530		
Iron and steelwork		410		
Railings		1 090		
Scum-boards		990	66 730	
Blow-off from Septic Tanks.				
3 ft. 4-in. by 5 ft., from septic tanks to blow-off gate-chamber....210 lin. ft.		1 830		
Blow off gate-chamber		1 250		
4-ft., from blow-off gate-chamber to main outlet....60 lin. ft.		370		
Main outlet		1 830		
16-in. sludge drain and river outlets, 240 lin. ft.		1 430	6 710	
Walk on influent conduit wall....490 lin. ft.			1 620	
5 ft. 6-in. influent conduit from septic tanks to gate-house....570 lin. ft.			5 890	
Gate-house....61 500 cu. ft.				
Substructure....31 700 cu. ft.				
Earthwork	$390			
Concrete	7 940			
Steel reinforcement	900			
Vitrified sewer pipe	70			
Iron and steelwork	710			
Sluice-gates	9 650			
Controlling, indicating, and recording devices	3 770	23 430		
Superstructure....29 800 cu. ft.		7 620		
Furniture and Equipment.				
Furniture and fittings	240			
Laboratory equipment	1 620	1 860	32 910	
Carried forward			$139 490	$741 830

TABLE 14.—(*Continued.*)

Brought forward			$139 490	$741 830
SEWAGE PURIFICATION WORKS (*Continued*).				
Sprinkling Filters ..... 10 acres				
Earthwork		$13 930		
Floors and main collectors		26 200		
Free draining bottom		34 000		
Walls ..... 3 950 lin. ft.		11 700		
Manholes 44		1 070		
Distribution System.				
30-in. main distributors ..... 3 430 lin. ft.	$7 480			
5-in. lateral distributors ... 18 190 lin. ft.	8 390			
6-in. lateral distributors .. 10 060 lin. ft.	4 970			
Risers and nozzles 2 108	6 860	27 700		
Filtering material ..... 80 120 cu. yd.		125 800	240 400	
5 ft. 6-in. Effluent Conduit.				
From gate-house to inlet gate-chamber ..... 480 lin. ft.		6 000		
From inlet gate-chamber to outfall gate-chamber ..... 300 lin. ft.		3 430		
Outfall gate-chamber		1 940		
From outfall gate-chamber to outfall ..... 40 lin. ft.		650		
Outfall		2 360	14 380	
Inlets to Settling Basins.				
Inlet gate-chamber		2 340		
5 ft. 6-in. inlet conduits ..... 540 lin. ft.		5 530		
21-in. pipe inlets ..... 480 lin. ft.		440	8 310	
Settling Basins ..... 4 000 000 gal.				
Earthwork		25 620		
Concrete		12 160		
Iron and steelwork		140	37 920	
Outlets from Settling Basins.				
5 ft. 6-in. outlet conduits to outlet gate-chambers ..... 50 lin. ft.		720		
Outlet gate-chambers		2 140		
5 ft. 6-in. outlet conduits, from outlet gate-chambers to outfall gate-chamber ..... 180 lin. ft.		2 520		
21-in. pipe drains to suction well .. 150 lin. ft.		340	5 720	
Suction Well			220	
Pump House.				
Building.				
Substructure	1 020			
Superstructure ..... 9 900 cu. ft.	1 990	3 010		
Machinery		3 610		
Suction and discharge piping		820	7 440	
Sludge Force Mains.				
16-in. main to river, including outlets ..... 220 lin. ft.		1 250		
15-in. main to south end of works. 520 lin. ft.		360	1 610	
Expenses Unclassified			860	456 350
Total Cost, Exclusive of Engineering				$1 198 180
ENGINEERING, 8.98 per cent.				
Pay-roll			90 820	
Supplies			6 450	
Expenses			10 280	107 550
TOTAL COST				$1 305 730
EXPERIMENTAL INVESTIGATION				45 290
TOTAL COST, INCLUDING EXPERIMENTAL INVESTIGATION				$1 351 020

TABLE 15.—UNIT COSTS OF MAIN FEATURES OF WORK.

Work.	Capacity.	Total cost.	Unit costs.
Buildings.			
East Side Sewage Pumping Station.			
Superstructure	25 700 cu. ft.	$5 480	21.3 cents per cu. ft.
Main Sewage Pumping Station.			
Substructure	110 200 cu. ft.	25 710	23.4 " " " "
Superstructure	248 600 cu. ft.	29 010	11.7 " " " "
Total	358 800 cu. ft.	54 720	15.3 " " " "
Gate-House, Sewage Purification Works.			
Substructure	31 700 cu. ft.	23 430	73.9 " " " "
Superstructure	29 800 cu. ft.	7 620	25.6 " " " "
Total	61 500 cu. ft.	31 050	50.5 " " " "
Pump House, Sewage Purification Works.			
Superstructure	9 900 cu. ft.	1 990	20.1 " " " "
Septic Tanks	8 020 000 gal.	$66 730	$8 320 per million gallons.
Sprinkling Filters	10 acres	240 400	24 040 per acre.
Settling Basins	4 000 000 gal.	37 920	9 480 per million gallons.
Sewage Purification Works.			
Levee, railroad spurs and culvert		$15 530	$780
Roads, walks, grading and drainage of grounds		3 590	180
Water and gas mains		6 510	330
Septic tanks		66 730	3 340
Blow-off from septic tanks		6 710	340
Walk on influent conduit wall		1 620	80
Influent conduit		5 890	290
Gate-house		32 910	1 640
Sprinkling filters	20 000 000 gal. per 24 hours	240 400	12 020 per million gallons per 24 hours.
Effluent conduit		14 380	720
Inlets and outlets to settling basins		14 030	700
Settling basins		37 920	1 900
Pump-house and suction well		7 660	380
Sludge force mains		1 610	80
Expenses unclassified		860	40
Total		$456 350	$22 820

TABLE 16.—SEWAGE PURIFICATION WORKS.—Records of Operation for January, 1909.

Day of Month.	Temperature, Degrees, Fahr. Air. Maximum.	Temperature, Degrees, Fahr. Air. Minimum.	Temperature, Degrees, Fahr. Sewage.	Rainfall, in inches.	Volume pumped, in millions of gallons per day.	Flow in septic tanks, average period, in hours.	Volume filtered, in millions of gallons per day.	Filter area in service, in acres.	Average rate of filtration, in millions of gallons per acre per day.	Flow in settling basin, average period, in hours.	Analytical Results, Parts per Million. Suspended Matter. Screened sewage.	Suspended Matter. Septic effluent.	Suspended Matter. Filter effluent.	Suspended Matter. Settling basin effluent.	Oxygen Consumed. Screened sewage.	Oxygen Consumed. Septic effluent.	Oxygen Consumed. Settling basin effluent.	Final Effluent. Dissolved oxygen.	Final Effluent. Putrescibility (odor) incubated 24 hrs. @ 37° C.	Final Effluent. Nitrites.	Final Effluent. Nitrates.	Bacteria. Millions per c c. Screened sewage.	Bacteria. Septic effluent.	Bacteria. Filter effluent.	Bacteria. Settling basin effluent.
1	30	16	56	0.00	9.52	11.6	9.52	2.50	3.80	10.0	224	77	....	36	110	44	26	4.8	N	0.12	0.60	3.08	0.64	0.46	1.06
2	38	21	56	0.00	11.01	10.0	11.01	2.85	3.86	9.0	376	89	....	37	86	45	27	4.4	?	0.12	0.52	1.84	1.00	0.88	0.84
3	49	36	55	0.01	10.83	10.0	10.83	2.80	3.86	9.0	252	112	....	41	97	44	26	3.1	?	0.11	0.49	4.50	0.64	0.40	1.20
4	56	44	56	0.21	14.82	7.5	14.82	3.25	4.56	6.5	1 088	138	....	39	192	72	35	2.2	P	0.14	0.58	1.50	1.12	1.10	0.90
5	53	37	56	0.17	16.40	6.7	16.40	3.95	4.15	5.8	740	160	....	81	136	65	43	3.2	P	0.07	0.36	1.25	1.00	1.10	1.00
6	37	10	56	0.02	11.82	9.3	11.82	3.12	3.96	8.0	268	124	....	66	94	62	37	2.6	?	0.05	0.51	2.35	0.94	1.00	1.40
7	21	10	55	tr.	12.20	9.0	12.20	3.12	3.91	8.0	220	108	....	54	79	57	34	6.0	N	0.04	0.31	2.70	1.10	1.00	1.10
8	30	16	55	0.00	11.70	9.4	11.70	3.05	3.84	8.0	232	90	....	44	102	62	31	6.3	?	0.07	0.36	3.00	0.80	0.56	0.80
9	41	29	56	0.02	11.20	10.0	11.20	3.12	3.60	8.5	218	108	....	38	94	56	32	5.0	P	0.10	0.30	1.16	1.38	0.92	0.92
10	51	39	56	0.04	10.26	10.0	10.26	2.80	3.66	9.3	442	106	....	46	121	55	30	1.3	P	0.12	0.27	5.30	1.00	1.22	1.34
11	31	20	56	0.22	13.24	7.6	13.24	3.12	4.62	6.6	302	100	....	70	115	66	35	2.2	?	0.15	0.75	4.95	0.70	1.02	0.80
12	14	10	56	0.17	13.33	7.6	13.33	2.92	4.98	6.6	252	86	....	56	108	71	40	6.2	N	0.07	0.76	2.80	1.14	1.00	0.70
13	23	6	54	0.30	14.74	6.8	14.74	3.40	4.32	6.5	270	108	....	64	95	62	37	7.2	N	0.23	0.42	2.72	0.88	0.74	0.90
14	41	23	55	tr.	15.61	6.5	15.61	3.75	4.16	6.2	296	169	....	57	93	66	35	6.7	N	0.18	0.12	3.56	1.08	0.58	....
15	37	20	53	tr.	18.65	5.4	18.65	4.60	4.05	5.2	328	136	....	66	99	60	37	6.0	P	0.26	0.52	1.72	0.64	0.40	0.56
16	30	24	53	0.32	14.66	6.8	14.66	3.85	3.80	6.5	242	116	....	63	93	56	37	6.3	P	0.20	0.70	1.28	0.44	0.32	0.60
17	27	22	52	tr.	12.28	15.6	12.28	2.95	4.54	7.8	158	90	....	44	86	60	37	5.7	P	0.22	0.40	2.60	0.34	0.25	0.50
18	27	17	54	tr.	11.45	16.7	11.45	3.33	3.44	8.4	274	100	....	34	99	61	26	5.6	N	0.16	0.49	3.90	0.52	0.37	0.30
19	33	21	54	0.00	7.10	27.0	7.10	2.50	3.58	13.5	202	84	....	46	84	63	29	3.2	P	0.12	0.58	......	......	....	....
20	34	25	54	0.00	11.03	17.5	11.03	3.00	3.68	8.7	242	86	....	37	92	63	25	2.4	P	0.14	0.86	......	......	....	....
21	54	33	53	0.00	11.80	16.3	11.80	3.44	3.43	8.1	596	112	....	55	117	64	29	3.6	P	0.16	0.89	......	......	....	....
22	62	47	51	0.12	10.89	17.6	10.89	2.95	4.05	8.8	360	118	....	71	88	65	30	4.2	P	0.25	1.05	......	......	....	....
23	62	53	56	0.28	14.19	13.5	14.19	4.06	3.49	6.7	710	132	....	57	117	53	22	5.0	P	0.65	1.00	1.92	0.96	0.70	0.70
24	66	57	56	0.00	11.28	17.0	11.28	2.80	4.00	8.5	218	84	....	61	56	46	30	4.1	P	0.50	1.15	2.64	0.48	0.62	0.70
25	50	39	55	0.00	11.45	17.0	11.45	2.80	4.10	8.4	378	80	....	28	94	46	18	4.2	P	0.60	0.97	5.92	1.30	0.84	1.14
26	46	29	56	0.00	10.61	18.0	10.61	2.80	3.80	9.0	396	102	....	38	90	72	31	1.5	P	0.21	1.30	2.36	0.80	0.88	1.40
27	44	30	56	0.00	10.06	19.0	10.06	2.80	3.60	9.5	166	88	....	37	84	65	24	4.2	P	0.21	1.17	1.76	2.30	2.52	1.96
28	38	26	56	0.04	6.29	30.0	6.29	2.50	3.70	......	180	68	....	36	78	56	26	......	....	0.35	0.40	......	......	....	....
29	43	24	54	0.39	8.60	22.0	8.60	2.50	3.40	......	518	109	74	....	104	60	30	7.1	P	0.12	1.20	2.16	0.66	0.74	....
30	29	14	54	0.21	9.97	19.0	9.97	2.80	3.60	......	280	109	84	....	91	50	30	8.7	P	0.25	0.85	1.72	0.22	0.24	....
31	15	4	54	tr.	9.34	20.0	9.34	2.50	3.70	......	109	80	84	....	45	41	26	9.2	N	0.32	0.73	1.60	0.60	0.50	....
Avge.	39	26	55	....	11.80	13.0	11.80	3.10	3.90	8.0	340	105	81	50	100	60	30	4.6	....	0.20	0.65	2.70	0.90	0.80	0.80

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for February, 1909.

Day of Month.	Temperature, Degrees, Fahr.			Rainfall, in inches.	Volume pumped, in millions of gallons per day.	Flow in septic tanks, average period, in hours.	Volume filtered, in millions of gallons per day.	Filter area in service, in acres.	Average rate of filtration, in millions of gallons per acre per day.	Flow in settling basin, average period, in hours.	Analytical Results, Parts per Million.										Bacteria.			
	Air.										Suspended Matter.			Oxygen Consumed.			Final Effluent.				Millions per c. c.			
	Maximum.	Minimum.	Sewage.								Screened sewage.	Septic effluent.	Settling basin effluent.	Screened sewage.	Septic effluent.	Settling basin effluent.	Dissolved oxygen.	Putrescibility (odor) incubated 24 hrs. @ 37° C.	Nitrites.	Nitrates.	Screened sewage.	Septic effluent.	Filter effluent.	Settling basin effluent.
1	23	0	52	0.00	10.2	19	10.2	2.7	3.8	......	172	70	50	74	39	22	9.6	N	0.15	0.92	3.00	0.50	0.50	......
2	40	17	53	0.00	10.5	18	10.5	2.5	4.2	......	176	85	71	74	48	28	7.3	N	0.35	0.92	1.80	0.80	0.70	......
3	44	30	53	0.00	11.0	17	11.0	3.6	3.1	4.5	210	114	59	74	52	29	6.2	P	0.22	0.88	1.60	0.75	0.75	0.90
4	56	34	52	0.00	12.2	16	12.2	3.4	3.6	4.0	214	114	59	67	54	27	5.2	P	0.45	0.10	2.75	0.55	0.60	0.80
5	56	41	53	0.31	13.7	14	13.7	3.3	4.2	3.5	320	89	76	72	62	27	......	P	0.05	0.45	......	......	......	......
6	41	34	53	0.08	12.2	16	12.2	3.3	3.7	4.0	522	142	74	100	47	23	7.2	P	0.50	0.65	0.80	0.40	0.45	0.40
7	40	30	52	0.00	14.1	13	14.1	3.0	4.7	7.0	134	103	51	37	38	20	6.6	P	0.75	0.90	1.40	0.46	0.43	0.55
8	43	28	55	0.00	17.4	11	17.4	4.5	3.85	5.5	191	106	32	71	46	19	8.1	N	0.60	1.19	1.60	0.48	0.40	0.24
9	48	36	53	0.40	21.4	9	21.4	5.6	3.85	4.5	451	164	81	83	47	26	6.6	P	0.32	0.73	1.20	0.70	0.44	0.38
10	48	21	51	tr.	20.0	9	20.0	6.2	3.25	5.0	275	155	77	72	46	24	9.4	PN	0.70	2.74	0.88	0.42	0.16	0.28
11	36	30	52	0.00	12.6	15	12.6	3.1	4.05	7.5	182	94	54	53	34	24	8.4	PN	0.67	1.53	0.40	0.62	0.28	0.34
12	48	29	54	0.54	13.7	14	13.7	3.2	4.25	7.0	179	86	57	61	37	25	7.3	P	0.68	0.42	1.30	0.50	0.35	0.30
13	52	41	52	0.01	16.5	12	16.5	4.0	4.10	6.0	359	150	63	78	42	24	6.5	P	0.50	1.02	0.95	0.25	0.20	0.30
14	60	37	51	0.56	18.7	10	18.7	5.0	3.75	......	580	116	72	70	34	22	9.3	N	0.86	2.16	1.20	0.40	0.30	......
15	38	27	49	0.42	17.8	11	5.2	4.6	......	......	460	118	75	68	32	18	10.6	N	0.70	4.47	1.30	0.30	0.20	......
16	28	20	48	0.24	18.4	......	......	......	......	......	278	132	....	47	49	....	......	......	....	......	0.60	0.10	......	......
17	32	17	49	0.00	18.5	10	9.12	4.4	4.15	......	174	120	....	55	42	....	......	P	....	......	1.20	0.40	0.30	......
18	50	29	49	0.00	18.8	10	18.8	5.0	3.70	......	212	98	52	53	34	22	10.2	N	0.76	5.39	1.45	0.50	0.25	......
19	52	38	49	0.21	19.0	10	19.0	5.0	3.80	......	264	100	80	47	28	20	9.7	N	0.70	7.20	0.75	0.30	0.30	......
20	44	33	45	0.00	19.6	10	6.24	5.0	3.75	......	190	120	52	24	26	17	......	N	0.76	6.84	0.15	0.20	....	......
21	49	32	44	tr.	20.9	......	......	......	......	......	170	102	....	14	17	....	......	......	....	......	0.06	0.18	......	......
22	55	29	44	0.00	21.2	......	......	......	......	......	110	104	....	13	15	....	......	......	....	......	0.03	0.05	......	......
23	64	42	46	2.05	15.8	......	......	......	......	......	814	174	....	72	30	....	......	......	....	......	0.50	0.25	......	......
24	61	35	51	0.14	8.9	......	......	......	......	......	724	230	....	58	27	....	......	......	....	......	0.25	0.10	......	......
25	35	19	49	tr.	10.4	......	......	......	......	......	292	186	....	18	18	....	......	......	....	......	0.20	0.20	......	......
26	46	22	48	0.00	10.5	......	......	......	......	......	200	142	....	17	16	....	......	......	....	......	0.12	0.07	......	......
27	51	31	49	tr.	10.8	......	......	......	......	......	84	100	....	8	13	....	......	......	....	......	0.08	0.05	......	......
28	39	30	50	0.01	9.7	......	......	......	......	......	58	104	....	7	14	....	......	......	....	......	0.06	0.10	......	......
Avge.	46	29	50	....	15.2	12	13.8	4.1	3.90	5.0	285	120	65	53	35	23	8.0	....	0.54	2.11	0.95	0.35	0.35	0.45

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for March, 1909.

Day of Month.	Temperature, Degrees, Fahr. Air. Max.	Temperature, Degrees, Fahr. Air. Min.	Temperature, Degrees, Fahr. Sewage.	Rainfall, in inches.	Flow in septic tanks, av. period, in hours.	Volume filtered, in mill. of gal. per day.	Filter area in service, in acres.	Av. rate of filtration, in millions of gallons per acre per day.	Flow in settling basin, av. period, in hrs.	Analytical Results, Parts per Million. Suspended Matter. Screened sewage.	Suspended Matter. Septic effluent.	Suspended Matter. Filter effluent.	Suspended Matter. Settling basin effluent.	Oxygen Consumed. Screened sewage.	Oxygen Consumed. Septic effluent.	Oxygen Consumed. Filter effluent.	Oxygen Consumed. Settling basin effluent.	Final Effluent. Dissolved oxygen.	Final Effluent. Putrescibility (odor) incubated 24 hrs. @ 37° C.	Final Effluent. Nitrites.	Final Effluent. Nitrates.	Bacteria. Millions per c. c. Screened sewage.	Bacteria. Septic effluent.	Bacteria. Filter effluent.	Bacteria. Settling basin effluent.
1	57	28	53	0.35	16	5.50	2.50	3.77	......	84	68	38	....	26	13	9	....	10.7	N	0.60	11.34	0.50	0.04	0.04	....
2	54	39	53	0.14	14	14.23	3.23	4.43	......	89	83	59	....	25	21	14	....	11.3	N	1.18	8.86	0.41	0.38	0.42	....
3	58	39	53	0.22	11	16.69	3.75	4.45	......	130	84	73	....	41	29	17	....	11.7	N	1.10	6.25	0.65	0.48	0.35	....
4	40	24	53	0.00	11	17.49	4.06	4.32	......	92	80	59	....	41	29	18	....	11.2	NP	1.20	6.50	0.72	0.36	0.33	....
5	40	22	53	0.00	11	16.80	4.06	4.11	......	132	72	57	....	38	30	23	....	11.2	NP	1.20	5.12	0.54	0.40	0.42	....
6	47	38	53	0.01	13	15.03	3.75	4.00	......	118	84	54	....	48	31	22	....	10.5	N	0.90	5.70	0.70	0.34	0.43	....
7	......	....	51	0.00	......	15.53	3.75	4.14	......	130	76	40	....	27	28	19	....	10.3	N	0.90	4.85	1.10	0.38	0.21	....
8	55	34	54	0.03	......	18.20	4.06	4.15	......	236	96	58	....	48	30	15	....	10.5	P	1.18	6.48	1.35	0.62	0.36	....
9	59	42	51	0.98	......	9.70	4.50	2.60	......	378	142	72	....	48	30	20	....	9.2	P	1.06	6.20	0.42	0.38	0.30	....
10	56	38	51	tr.	......	......	......	......	......	186	122	....	....	21	22	......	....	......	....	......	......	0.24	0.18	....	....
11	42	32	51	0.00	......	4.35	2.50	3.48	......	286	86	46	....	26	14	11	....	10.4	N	0.42	7.48	0.15	0.16	0.03	....
12	50	30	51	tr.	......	11.05	2.50	4.42	......	106	82	49	....	11	12	10	....	10.7	N	0.46	6.14	......	0.12	....	....
13	48	39	52	0.00	......	17.34	4.17	4.16	......	172	82	46	....	28	15	11	....	10.2	NP	0.84	5.16	0.36	0.10	0.09	....
14	53	27	51	tr.	11	18.07	4.63	3.90	......	68	62	27	....	18	16	11	....	11.2	N	0.60	5.70	0.28	0.10	0.10	....
15	44	30	53	0.00	9.5	20.11	4.58	4.39	......	126	60	26	....	41	23	12	....	10.8	N	0.82	4.02	1.35	0.41	0.21	....
16	41	29	54	0.03	9.5	20.08	4.69	4.28	......	128	84	41	....	44	31	16	....	10.1	N	1.10	6.70	1.47	0.64	0.32	....
17	33	19	53	0.00	10	18.39	4.32	4.22	......	170	78	48	....	45	30	22	....	10.5	N	1.10	3.20	1.57	0.74	0.52	....
18	46	22	54	0.01	10	19.19	3.75	5.14	......	176	80	48	....	48	28	22	....	9.4	P	1.04	1.16	1.60	0.75	0.65	....
19	54	41	54	0.07	10	19.03	3.75	5.07	......	334	78	59	....	63	32	27	....	9.0	P	0.84	0.76	1.26	0.96	0.69	....
20	55	35	55	0.00	11	18.00	3.75	4.80	......	288	80	52	....	65	28	22	....	9.5	P	0.96	1.04	2.92	1.06	0.94	....
21	57	27	54	0.00	11	17.12	3.98	4.30	......	160	70	39	....	40	27	20	....	9.2	N	0.94	1.96	1.28	1.02	0.68	....
22	53	25	53	0.00	11	17.21	4.90	3.50	......	134	156	38	....	48	43	16	....	9.6	P	0.72	1.38	2.28	0.60	0.32	....
23	50	....	55	0.00	10	18.40	3.75	4.90	2.6	164	78	46	45	56	40	28	21	7.1	PN	0.44	1.26	1.76	0.71	0.53	0.50
24	62	32	55	0.65	11	17.37	4.06	4.20	2.7	350	106	49	44	74	38	20	21	6.2	P	0.29	0.91	2.44	1.52	1.07	0.89
25	57	33	52	0.18	11	17.96	4.58	3.90	2.7	260	152	82	67	61	37	20	18	8.0	P	0.42	2.78	0.78	0.54	....	0.66
26	50	30	53	0.00	10	18.00	4.17	4.30	2.7	110	79	43	41	40	34	15	14	9.2	PN	0.58	3.62	0.64	0.45	0.40	0.22
27	54	36	54	0.00	11	17.87	4.37	4.00	2.7	160	76	41	34	44	30	16	14	8.9	P	0.62	2.78	2.14	0.68	0.40	0.40
28	50	37	52	0.00	10	18.49	4.70	3.90	2.6	178	76	28	28	40	25	12	12	9.4	N	0.80	2.20	1.52	0.49	0.33	0.24
29	50	29	54	tr.	10	18.42	4.70	3.90	2.6	230	74	33	27	71	26	14	12	10.2	N	0.80	2.90	2.14	0.58	0.45	0.25
30	46	32	54	0.01	14	13.96	3.75	3.70	3.4	126	82	40	35	57	32	15	16	7.6	P	0.58	2.12	1.06	1.03	0.88	0.89
31	46	34	54	0.00	14	13.41	4.06	3.30	3.6	220	84	42	31	53	33	19	17	7.9	N	0.22	1.28	1.94	0.75	0.43	0.45
Avge.	50	32	53	....	11.6	16.10	3.98	4.12	2.8	178	87	47	39	43	28	17	16	9.7	....	0.80	4.20	1.18	0.55	0.43	0.50

NOTE.—All primary and secondary tanks in service continuously. Filters operated continuously for 6 hours, then rested for 6 hours, more or less, the length of the resting period being governed by the volume of sewage. The 6-hour period in service was split up as follows: First 2 hours, 3.0 ft. head on nozzles; second 2 hours, 6.0 ft. head on nozzles; third 2 hours, 9.0 ft. head on nozzles. Settling basins cleaned during first 3 weeks of the month.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for April, 1909.

Day of Month.	Temperature, Degrees, Fahr. Air. Max.	Air. Min.	Sewage.	Rainfall, in inches.	Volume pumped, in millions of gallons per day.	Flow in septic tanks, av. period, in hours.	Volume filtered, in mill. of gal. per day.	Filter area in service, in acres.	Av. rate of filtration, in millions of gallons per acre per day.	Flow in settling basin, av. period, in hrs.	Analytical Results, Parts per Million. Susp'd Matter. Screened sewage.	Susp'd Matter. Septic effluent.	Susp'd Matter. Filter effluent.	Susp'd Matter. Settling basin effluent.	Oxygen Cons'd. Screened sewage.	Oxygen Cons'd. Septic effluent.	Oxygen Cons'd. Filter effluent.	Oxygen Cons'd. Settling basin effluent.	Final Effluent. Dissolved oxygen.	Final Effluent. Putrescibility (odor) incubated 24 hrs. @ 37° C.	Final Effluent. Nitrites.	Final Effluent. Nitrates.	Bacteria. Millions per c. c. Screened sewage.	Bacteria. Septic effluent.	Bacteria. Filter effluent.	Bacteria. Settling basin effluent.
1	46	36	56	0.00	11.78	16	12.20	3.12	3.91	4	150	100	38	39	58	33	17	16	6.6	N	0.38	1.12	1.54	0.54	0.33	0.51
2	53	36	55	0.06	10.48	18	10.26	2.50	4.10	5	224	84	36	27	68	36	16	16	6.6	PN	0.26	1.14	1.10	0.59	0.39	0.59
3	54	34	55	0.01	8.17	23	9.02	2.50	3.61	5	108	90	40	31	40	35	16	16	6.2	N	0.25	0.75	1.60	1.10	0.75	0.37
4	......	....	55	0.00	5.39	36	6.99	2.50	2.40	7	54	84	38	35	20	30	18	16	6.0	P	0.20	1.10	0.70	0.30	0.20	0.45
5	74	34	55	0.00	6.95	27	4.29	2.35	2.40	8	68	56	22	18	48	26	13	13	4.9	P	0.23	0.67	1.26	0.13	.....	....
6	78	57	55	1.00	11.55	16.5	8.00	2.70	4.00	6	434	76	64	36	63	27	15	13	5.7	N	0.28	2.52	5.00	0.72	0.37	0.48
7	66	46	55	0.00	15.54	12	......	......	......	....	520	122	....	....	48	20	....	....	......	....	....	......	0.20	0.11	.....	...
8	54	34	52	tr.	13.26	14.5	......	......	......	....	116	90	....	....	27	18	....	....	......	....	....	......	0.16	0.14	.....	....
9	50	29	51	0.04	11.23	17	......	......	......	....	154	97	....	....	20	16	....	....	......	....	....	......	0.20	0.38	.....	....
10	41	23	52	tr.	11.61	16.5	6.23	2.80	4.45	....	128	88	63	....	38	18	17	....	11.5	N	0.80	7.00	0.61	0.04	0.28	....
11	52	26	52	0.00	10.89	17.5	11.13	2.97	3.75	4.4	54	50	58	....	14	18	14	....	11.2	N	1.15	4.40	0.36	0.34	0.13	0.12
12	66	45	53	0.00	10.04	19	10.04	2.92	3.44	4.8	80	46	42	20	30	14	10	8	10.5	N	1.10	3.40	0.57	0.27	0.11	0.11
13	72	54	54	0.16	9.94	20	9.07	2.81	3.22	5.2	86	62	49	....	21	18	13	12	7.5	N	0.75	2.75	0.45	0.89	0.65	0.46
14	57	35	54	0.00	9.15	21	9.32	2.50	3.73	5.1	80	42	41	21	35	21	13	....	7.8	P	0.46	1.40	0.57	0.98	0.88	0.46
15	63	32	55	0.00	8.89	21.5	8.38	2.29	3.66	5.7	106	44	39	13	97	25	22	14	7.7	PN	0.44	2.30	2.89	1.31	0.66	0.88
16	73	44	55	0.00	8.61	22.5	8.44	2.13	3.96	5.7	60	54	48	21	32	29	17	16	5.8	PN	0.52	2.50	0.96	0.86	0.73	0.65
17	77	56	55	tr.	8.55	22.5	9.23	2.50	3.70	5.2	106	52	40	9	26	23	15	14	6.3	PN	0.52	1.00	1.48	1.20	0.50	0.53
18	81	50	55	0.00	7.88	22	8.73	2.50	3.50	5.5	58	46	63	12	16	17	14	10	5.7	N	0.46	2.90	0.72	0.64	2.75	0.36
19	84	59	57	0.03	13.20	12	12.28	3.38	3.63	4.0	292	140	61	22	58	26	12	9	7.8	N	0.68	2.40	3.00	0.24	5.30	0.20
20	70	43	56	0.25	15.99	12	16.26	4.22	3.85	3.0	604	108	60	30	99	29	16	17	6.5	PN	0.58	2.00	3.64	0.58	0.80	0.65
21	72	46	57	0.48	15.81	11	15.74	4.48	3.51	6.0	410	84	75	48	96	30	17	15	4.2	PN	0.54	1.20	3.65	1.44	0.97	0.93
22	72	45	59	0.00	15.24	12.5	14.96	3.75	3.99	6.5	198	76	52	29	66	26	16	13	5.2	N	0.67	0.80	1.88	1.08	0.95	1.94
23	56	44	59	0.00	16.28	12	16.85	3.80	4.43	5.5	422	86	69	31	58	30	18	15	3.5	P	0.62	1.10	1.20	0.90	1.60	....
24	58	30	59	0.00	15.40	12.5	15.46	3.85	4.01	6.0	218	62	47	26	66	26	14	13	4.9	PN	0.62	1.70	1.76	0.80	0.48	0.81
25	70	38	58	0.34	14.24	13	13.41	3.23	4.15	7.0	122	66	64	10	34	26	16	10	4.8	PN	0.60	1.80	1.44	0.96	0.52	0.83
26	70	35	60	0.00	14.64	12.5	14.78	3.75	3.94	6.5	232	58	65	27	69	24	16	13	8.1	N	0.75	2.25	2.40	0.88	0.72	0.75
27	70	42	59	0.05	15.62	12	15.48	3.54	4.37	6.0	196	90	86	32	66	35	19	16	2.7	PN	0.63	1.80	2.24	1.20	0.76	1.31
28	70	34	59	tr.	15.13	12.5	15.00	3.59	4.18	6.5	288	74	113	28	72	31	21	16	0.6	P	0.58	1.80	1.94	1.42	0.82	1.28
29	81	45	60	tr.	14.79	12	14.93	3.59	4.16	6.5	116	94	100	30	58	35	25	15	3.9	PN	0.64	1.90	2.10	1.06	0.98	1.17
30	83	58	61	0.78	17.68	10.5	13.32	4.27	4.40	7.0	596	136	116	22	76	36	23	18	4.0	P	0.64	2.30	1.46	1.10	0.67	1.13
Avge.	66	41	56	....	12.13	16.9	11.47	3.13	3.80	5.66	209	78	59	26	57	26	16	14	6.2	....	0.57	2.08	1.57	0.74	0.90	0.71

NOTE.—All primary and secondary tanks in service continuously. Operation of filters to April 22d, same as in March. April 22d, method of operation changed as follows: Period of service reduced to 2 hours, and the length of the resting period determined by the volume of sewage pumped. A single head used on the nozzles throughout the period in service with the following heads alternating in order as follows: First period in service, 4.0 ft. head. Second period in service, 7.0 ft. head. Third period in service, 9.0 ft. head. Fourth period in service, 4.0 ft. head. Fifth period in service, 7.0 ft. head. Sixth period in service, 9.0 ft. head, etc.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for May, 1909.

Day of Month.	Temperature, Degrees, Fahr. Air. Maximum.	Temperature, Degrees, Fahr. Air. Minimum.	Temperature, Degrees, Fahr. Sewage.	Rainfall, in inches.	Volume pumped, in millions of gallons per day.	Flow in septic tanks, average period, in hours.	Volume filtered, in millions of gallons per day.	Filter area in service, in acres.	Average rate of filtration, in millions of gallons per acre per day.	Flow in settling basin, average period, in hours.	Analytical Results, Parts per Million. Suspended Matter. Screened sewage.	Suspended Matter. Septic effluent.	Suspended Matter. Filter effluent.	Suspended Matter. Settling basin effluent.	Oxygen Consumed. Screened sewage.	Oxygen Consumed. Septic effluent.	Oxygen Consumed. Filter effluent.	Oxygen Consumed. Settling basin effluent.	Final Effluent. Chlorine.	Final Effluent. Dissolved oxygen.	Final Effluent. Putrescibility (odor) incubated 24 hrs. @ 37° C.	Final Effluent. Nitrites.	Final Effluent. Nitrates.	Bacteria. Millions per c. c. Screened sewage.	Bacteria. Septic effluent.	Bacteria. Filter effluent.	Bacteria. Settling basin effluent.
1	70	39	57	tr.	17.60	10	....	....	....	....	406	180	....	....	28	23	....	....	17	....	....	....	....	0.60	0.10	....	....
2	51	34	54	tr.	13.75	13	....	....	....	....	410	300	....	....	22	23	....	....	20	....	....	....	....	0.52	....	....	....
3	53	35	53	0.36	11.79	15	....	....	....	....	254	170	....	....	22	17	....	....	18	....	....	....	....	....	....	....	....
4	54	35	56	0.50	10.49	16	....	....	....	....	218	76	....	....	35	21	....	....	38	....	....	....	....	1.92	0.97	....	....
5	....	....	53	0.17	9.01	19	4.11	2.50	3.30	....	132	128	364	....	19	27	45	....	24	....	....	0.68	7.10	0.25	0.59	0.70	....
6	78	56	57	0.00	12.82	14	12.34	3.12	4.00	....	144	58	740	....	38	15	40	....	52	....	....	0.74	5.30	1.42	0.60	....	....
7	84	52	59	0.01	14.26	12.5	14.60	3.65	4.00	....	300	60	164	....	45	24	26	....	80	9.2	PN	0.78	2.60	4.60	1.10	0.80	....
8	74	42	59	0.00	12.63	14.5	12.70	3.12	4.07	4	180	218	138	33	30	29	21	14	58	5.5	N	0.49	1.90	1.92	6.45	2.55	1.44
9	81	61	58	0.52	13.47	13.4	13.61	3.44	3.95	3.5	272	66	136	32	47	22	20	13	68	5.8	N	0.52	2.5	1.17	1.52	1.03	1.21
10	81	47	59	0.94	15.85	....	1.76	0.42	4.20	3.4	566	72	....	....	44	17	....	....	21	....	....	....	....	6.80	3.06	....	....
11	61	40	55	0.00	18.15	....	....	....	....	....	274	202	....	....	18	19	....	....	15	....	....	....	....	....	0.26	....	....
12	70	40	56	0.00	17.01	....	....	....	....	....	112	118	....	....	14	16	....	....	17	....	....	....	....	0.85	0.26	....	....
13	74	48	56	tr.	16.42	....	....	....	....	....	50	60	....	....	10	10	....	....	20	....	....	....	....	....	0.12	....	....
14	77	58	57	0.00	11.10	15.7	3.11	1.87	3.32	....	42	44	185	....	8	7	22	....	26	9.7	N	0.65	8.1	0.23	0.29	0.18	....
15	83	59	55	0.23	7.35	24	6.79	1.77	3.80	....	52	15	156	....	11	7	16	....	29	10.1	N	0.81	6.6	1.17	....	0.31	....
16	80	56	55	0.00	6.37	28	6.79	1.87	3.63	....	13	32	57	....	9	8	10	....	24	10.1	N	1.20	4.80	....	0.15	....	....
17	73	47	57	0.00	10.32	17	10.32	2.55	4.05	....	122	12	54	....	37	11	13	....	218	10.2	N	1.02	4.20	3.90	2.95	0.42	....
18	75	47	61	0.00	15.81	11.7	15.53	3.60	4.30	....	202	38	82	....	53	21	17	....	66	8.5	N	0.45	1.65	3.52	2.21	1.16	....
19	78	48	61	0.00	15.13	12	15.90	3.75	4.24	3.2	204	54	85	25	58	30	18	13	57	7.7	P	0.66	1.30	2.27	1.77	1.07	1.22
20	77	52	60	0.99	16.01	11.4	15.34	3.64	4.21	3.0	278	46	33	15	64	20	14	14	57	5.2	P	0.42	1.50	2.10	1.13	0.56	0.73
21	67	54	59	0.11	17.88	10.5	17.32	3.85	4.50	....	112	46	33	....	40	18	12	....	48	10.3	PN	0.83	2.60	0.60	0.65	0.33	....
22	71	50	61	0.00	16.92	10.9	17.92	4.43	4.04	....	142	58	42	....	50	18	16	....	66	10.9	N	1.14	1.80	1.65	1.00	0.39	....
23	74	48	60	0.00	14.28	12.6	14.00	3.44	4.07	....	88	30	14	....	32	16	13	....	62	7.6	N	0.58	1.20	1.45	0.98	0.30	....
24	76	51	60	0.00	14.81	12.5	14.40	3.44	4.18	3.3	188	44	78	21	54	16	13	9	72	5.4	N	0.55	2.4	2.86	0.93	0.36	0.14
25	72	54	60	0.07	14.72	12.4	15.29	3.44	4.44	3.1	168	51	21	23	50	21	10	13	53	6.2	PN	0.68	1.3	2.80	2.18	0.67	1.14
26	70	59	61	0.10	14.12	13.1	13.78	3.44	4.00	3.5	136	26	19	17	51	22	11	13	52	6.0	PN	0.75	1.65	3.85	0.85	0.56	0.99
27	76	61	62	0.08	13.67	13.3	13.67	3.54	3.86	3.5	198	54	59	28	59	29	17	17	....	4.8	N	0.80	2.7	2.40	1.72	1.23	1.20
28	76	56	61	0.00	13.53	13.4	13.53	3.38	4.00	3.5	180	34	44	20	60	26	17	13	70	3.6	PN	0.67	1.2	2.84	0.96	1.18	1.04
29	77	56	63	0.00	13.60	13.4	13.74	3.44	4.00	3.5	268	54	42	28	66	24	15	13	70	7.3	N	0.71	2.0	4.32	0.66	1.05	....
30	87	65	62	0.57	14.35	12.7	14.77	3.33	4.43	....	302	32	24	....	48	21	13	....	....	8.1	P	0.62	1.7	1.61	1.66	0.79	....
31	79	60	61	0.00	11.28	16.1	11.07	2.71	4.08	....	210	52	25	....	46	21	12	....	85	7.4	N	0.45	2.35	....	....	....	....
Avge.	70	50	58	....	13.7	14.4	12.18	3.07	4.03	3.4	200	78	118	24	38	19	18	13	52	7.6	....	0.70	2.93	2.20	1.30	0.80	1.00

NOTE.—Operation of filters same as in April report. All septic tanks cleaned out May 11th, 12th and 13th.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for June, 1909.

Day of Month.	Temperature, Degrees, Fahr. Air. Max.	Air. Min.	Sewage.	Rainfall, in in.	Volume pumped, in millions gal. per day.	Flow in septic tanks, av. period, in hrs.	Volume filtered, in millions gal. per day	Filter area in service, in acres.	Av. rate of filtration, in millions gal. per acre per day.	Suspended Matter. Parts per million. Screened sewage.	Septic effluent.	Filter effluent.	Oxygen Consumed. Parts per million. Screened sewage.	Septic effluent.	Filter effluent.	Final Effluent. Chlorine, parts per million.	Dissolved oxygen, parts per million.	Putrescibility (odor) incubated 24 hrs. @ 37° C.	Nitrogen. Nitrites, parts per million.	Nitrates, parts per million.	Bacteria. Millions per c.c. Screened sewage.	Septic effluent.	Filter effluent.
1	80	66	63	0.00	10.6	17.2	10.5	2.50	4.18	234	44	29	43	21	12	53	7.6	PN	0.50	2.50	.....	.....	.....
2	84	64	63	0.25	11.2	16.0	11.2	2.60	4.32	106	64	22	40	29	12	48	6.9	P	0.43	1.60	.....	.....	.....
3	79	65	63	0.01	10.4	17.5	10.4	2.70	3.85	124	39	21	41	20	11	52	6.6	PN	0.41	1.40	3.20	0.96	0.92
4	79	66	65	0.07	11.0	16.7	10.9	2.50	4.36	236	34	28	47	20	11	51	7.2	N	0.50	2.70	9.00	......	0.72
5	84	63	65	0.07	11.9	15.4	12.0	2.70	4.44	188	32	21	46	18	9	54	7.1	N	0.58	2.50	6.91	1.76	0.95
6	84	56	65	0.00	11.7	15.5	11.9	2.90	4.10	96	43	49	16	15	12	58	6.8	N	0.56	2.50	4.00	1.35	0.92
7	88	64	65	tr.	11.2	16.4	10.9	2.60	4.20	164	36	57	44	13	12	52	8.0	N	0.94	3.76	8.20	1.54	0.70
8	90	64	65	0.67	11.7	15.6	12.0	2.50	4.80	174	31	102	42	19	16	53	7.3	N	0.58	3.22	6.16	1.97	0.70
9	92	64	67	tr.	12.5	14.5	12.5	2.60	4.80	208	38	81	39	20	14	29	7.1	N	0.60	2.30	2.76	1.84	0.48
10	84	64	66	0.24	12.5	14.7	12.5	2.90	4.30	194	31	148	30	14	......	32	7.9	N	0.68	3.07	3.00	1.98	0.33
11	77	60	67	tr.	13.5	13.6	13.5	3.25	4.16	331	38	52	31	15	......	20	8.0	N	0.70	1.90	0.72	1.00	0.32
12	81	56	67	0.00	12.9	8.6	12.6	3.10	4.05	184	53	38	29	13	......	32	9.0	N	0.85	3.00	4.92	0.76	0.28
13	88	56	66	0.00	13.3	8.0	13.4	2.90	4.60	......	......	......	......	......	......	......	......	......	......	......	......	......	......
14	84	56	66	0.00	12.7	8.6	12.7	3.10	4.10	......	......	......	......	......	15.6	......	8.3	......	......	4.65	5.72	2.63	0.52
15	83	57	67	0.00	14.7	7.5	14.7	3.20	4.60	204	50	48	56	22	......	51	......	......	......	3.50	4.25	1.98	0.65
16	80	56	66	0.00	13.4	8.2	13.1	3.30	4.00	......	......	......	59	36	14.8	......	7.6	......	......	2.22	3.50	1.77	0.70
17	84	54	67	0.30	14.0	7.8	14.2	3.30	4.25	366	55	93	74	36	......	57	......	......	......	2.32	1.46	1.50	0.66
18	76	52	67	0.00	12.6	8.6	12.5	3.30	3.75	......	......	......	56	36	19.0	......	7.1	......	......	3.72	2.04	0.83	0.40
19	81	47	66	0.00	13.0	8.5	12.8	3.00	4.30	96	43	124	51	34	......	61	......	......	......	2.72	3.18	1.71	0.74
20	90	49	65	0.00	12.2	9.0	12.5	2.90	4.30	......	......	......	......	......	......	......	......	......	......	......	......	......	......
21	87	66	68	0.32	15.4	7.2	15.3	3.45	4.44	......	......	......	72	33	15.4	......	5.8	......	......	......	5.02	1.42	1.02
22	83	68	70	0.03	17.0	6.5	16.9	3.75	4.50	284	78	62	59	36	......	61	......	......	......	2.95	2.15	1.00	0.20
23	84	67	70	1.01	16.7	6.7	16.4	3.65	4.48	......	......	......	63	40	12.2	......	6.6	......	......	......	1.98	0.78	0.19
24	87	66	68	0.12	16.0	7.0	15.8	3.55	4.45	282	67	35	52	28	......	64	......	......	......	2.38	1.50	0.63	0.27
25	90	66	69	0.49	15.7	7.0	15.7	3.55	4.42	......	......	......	56	25	13.7	......	6.8	......	......	......	3.32	1.03	0.39
26	91	67	69	0.00	15.8	6.9	15.8	3.45	4.58	344	101	33	44	24	......	57	......	......	......	3.30	1.44	0.57	0.28
27	94	73	69	0.23	15.1	7.3	15.2	3.65	4.20	......	......	......	......	......	......	......	......	......	......	......	......	......	......
28	92	71	70	0.07	14.8	7.5	14.8	3.55	4.20	......	......	......	41	26	11.8	......	7.3	PN	......	......	1.55	0.80	0.25
29	92	71	71	0.00	14.5	7.5	14.2	3.50	4.05	242	70	32	39	19	......	54	......	N	......	3.65	2.11	0.58	0.28
30	89	60	71	0.00	13.9	7.7	14.2	3.15	4.50	......	......	......	38	27	10.4	......	7.7	PN	......	......	3.26	0.76	0.26
Avge.	86	61	67	....	13.4	10.6	13.4	3.10	4.30	214	49	56	46	24	13	49	7.3	......	......	......	3.65	1.29	0.52

NOTE.—Until June 13th analyses of filter effluent were made on the combined effluent of all filters.

Beginning June 14th Filter 7 has been operated on a 15-min. schedule and Filter 8 on a schedule alternating 6 hours run and 6 hours rest; tests for suspended matter, since that time, have been made on the combined effluent of Filters 7 and 8; the oxygen consumed has been determined from the effluent from Filter 7, and the bacterial content is the average of the samples taken from Filters 7 and 8.

Between June 13th and June 28th, putrescibility tests by odor were omitted.

The settling basins were out of service, on account of the construction of the retaining walls.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for July, 1909.

Day of Month.	Temperature, Degrees, Fahr. Air. Max.	Air. Min	Sewage.	Rainfall, in in.	Volume pumped, in millions gal. per day.	Flow in septic tanks, av. period, in hrs.	Volume filtered, in millions gal. per day.	Filter area in service, in acres.	Av. rate of filtration, in mill. gal. per acre per day.	Analytical Results, Parts per Million. Susp'd Matter. Screened sewage.	Susp'd Matter. Septic effluent.	Susp'd Matter. Filter effluent.	Oxygen Cons'd. Screened sewage.	Oxygen Cons'd. Septic effluent.	Oxygen Cons'd. Filter effluent.	Final Effluent. Chlorine.	Final Effluent. Dissolved oxygen.	Final Effluent. Putrescibility (odor) incubated 24 hrs. @ 37° C.	Final Effluent. Nitrates.	Bacteria. Millions per c. c. Screened sewage.	Bacteria. Septic effluent.	Bacteria. Filter effluent.
1	95	64	70	0.00	14.82	7.4	14.63	3.55	4.10	194	89	32	42	28	......	58	......	PN	2.30	3.08	0.59	0.19
2	93	64	69	0.60	15.73	6.9	15.80	3.45	4.60	......	......	......	45	32	13.9	......	6.4	PN	......	2.02	0.61	0.15
3	77	64	70	tr.	14.99	7.3	14.95	3.45	4.30	162	98	47	47	30	......	76	......	PN	2.62	1.76	0.44	0.18
4	76	65	69	0.00	13.08	5.6	13.23	3.45	3.85	......	......	......	......	......	......	......	......	......	......	......	......	......
5	70	58	69	0.09	14.07	5.5	14.00	3.40	4.10	......	......	......	56	34	14.3	......	8.0	N	......	1.29	0.52	0.19
6	82	58	68	0.01	9.94	7.6	9.90	3.30	3.00	198	106	43	67	45	15.4	69	6.6	PN	3.40	1.21	0.60	0.29
7	89	65	70	0.00	18.40	4.3	18.37	3.40	5.40	......	......	......	66	47	15.0	......	7.0	PN	......	2.50	0.94	0.41
8	89	66	70	0.00	14.04	5.5	14.07	3.45	4.10	160	114	42	64	47	12.3	58	6.2	PN	1.85	5.77	1.12	0.40
9	90	65	68	0.00	8.44	8.2	8.62	2.30	3.70	......	......	......	44	44	11.4	......	6.2	PN	......	2.78	0.89	0.14
10	86	73	63	0.00	5.16	14.4	5.00	1.40	3.60	160	104	80	24	37	......	49	......	PN	3.25	0.80	0.45	0.26
11	78	69	63	0.16	5.74	13.5	5.92	1.50	3.95	......	......	......	......	......	......	......	......	......	......	......	......	......
12	86	67	64	1.11	8.08	9.5	8.08	1.65	4.90	......	......	......	32	26	23	......	5.8	PN	......	0.66	0.25	0.08
13	87	69	66	0.38	9.38	8.0	9.32	2.15	4.35	122	84	197	29	27	23	28	7.1	N	4.00	0.76	1.00	0.35
14	85	71	65	tr.	9.35	8.0	9.50	2.05	4.60	......	......	......	29	28	38	......	5.4	PN	......	1.04	0.78	0.27
15	90	67	68	0.57	9.13	8.0	6.86	1.55	4.40	62	106	186	24	26	24	......	7.1	N	3.65	......	......	......
16	82	66	67	0.23	9.40	8.0	9.36	2.00	4.70	......	......	......	23	17	51	......	6.2	N	......	0.65	0.22	0.15
17	82	63	67	0.00	9.65	7.7	9.70	2.30	4.20	100	44	259	19	14	......	31	......	N	4.05	0.36	0.24	0.07
18	82	51	68	0.01	9.50	8.1	9.30	2.30	4.00	......	......	......	......	......	......	......	......	......	......	......	......	......
19	78	57	69	0.00	10.00	7.7	10.10	2.30	4.40	......	......	......	29	14	24.3	......	7.2	N	......	0.72	0.08	0.03
20	87	64	68	0.00	10.60	7.2	10.50	2.20	4.80	104	43	118	33	23	20.6	40	7.6	N	3.32	1.47	0.38	0.13
21	82	65	68	0.00	10.50	7.0	10.70	2.20	4.90	......	......	......	23	21	25.2	......	7.3	N	......	0.67	0.55	0.19
22	86	68	68	0.40	10.50	7.2	10.40	2.10	5.00	52	18	43	42	21	20.6	40	6.9	N	3.80	0.94	0.66	0.13
23	66	59	68	0.03	10.70	7.0	10.70	2.20	4.90	......	......	......	37	21	20.3	......	7.7	N	......	0.68	0.52	0.15
24	85	65	66	0.00	10.30	7.4	10.20	2.20	4.60	60	39	55	28	18	......	35	......	N	3.85	0.63	0.83	0.06
25	85	65	66	0.00	......	8.7	9.00	2.50	3.60	......	......	......	......	......	......	......	......	......	......	......	......	......
26	80	65	66	0.02	......	9.4	8.80	1.95	4.50	......	......	......	28	15	12.4	......	8.0	N	......	0.62	0.30	0.06
27	77	72	66	0.02	......	8.0	8.80	2.05	4.30	85	53	51	39	29	14.5	40	7.1	N	4.40	1.04	0.58	0.06
28	87	62	68	0.00	......	7.5	9.70	2.05	4.70	......	......	......	32	40	14.5	......	6.4	N	......	1.25	0.62	0.17
29	90	65	69	0.08	......	8.2	8.90	2.05	4.30	74	73	51	53	30	15.7	42	6.5	N	3.57	0.78	0.36	0.07
30	93	70	69	0.18	......	8.0	9.30	1.95	4.80	......	......	......	34	30	13.2	......	6.7	N	......	0.75	0.50	0.09
31	85	60	69	tr.	......	8.3	9.20	2.05	4.50	70	63	67	33	34	......	50	......	N	3.98	0.87	0.40	0.07
Avge.	84	65	67	......	10.90	7.9	10.42	2.40	4.36	115	74	91	38	29	20.1	47	6.8	....	3.43	1.35	0.54	0.17

NOTE.—Chlorine, oxygen consumed, dissolved oxygen, and putrescibility determinations in the filter effluent are made on samples taken from the effluent from Filter 7. Suspended matter in the filtered sewage is determined from composite samples taken from Filters 7 and 8, and the nitrites and nitrates and the bacterial content in the filtered sewage are the averages of analyses from Filters 7 and 8. Filter 7 has been operated on the 15-min. schedule, and Filter 8 on the 6-hour schedule. The divisions of the septic tanks in service have been: July 1st to 3d, inclusive, Nos. 2, 3, 4, and 6. July 4th to 14th, inclusive, Nos. 4 and 6. July 15th to 31st, inclusive, Nos. 4 and 5. The settling basins were out of service throughout the month, on account of the construction of the retaining walls. On July 9th, the intercepting sewer was shut off at Mound Street, all sewage above this point flowing direct to the river. On July 12th, river water was admitted to the pump suctions with the intent to keep the flow of sewage at about 10 000 000 gal. per day.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for August, 1909.

Day of Month.	Temperature, Degrees, Fahr. — Air. Max.	Temperature — Air. Min.	Temperature — Sewage.	Rainfall, in inches.	Flow in septic tanks, av. period, in hours.	Volume filtered, in mill. of gal. per day.	Filter area in service, in acres.	Av. rate of filtration, in millions of gallons per acre per day.	Flow in settling basin, av. period, in hrs.	Analytical Results, Parts per Million. Suspended Matter. Screened sewage.	Suspended Matter. Septic effluent.	Suspended Matter. Filter effluent.	Suspended Matter. Settling basin effluent.	Oxygen Cons'd. Screened sewage.	Oxygen Cons'd. Septic effluent.	Oxygen Cons'd. Filter effluent.	Oxygen Cons'd. Settling basin effluent.	Final Effluent. Chlorine.	Final Effluent. Dissolved oxygen.	Final Effluent. Putrescibility (odor) incubated 24 hrs. @ 37° C.	Final Effluent. Nitrates.	Bacteria. Millions per c. c. Screened sewage.	Bacteria. Septic effluent.	Bacteria. Filter effluent.	Bacteria. Settling basin effluent.
1	95	72	68	0.00	8.1	9.04	1.95	4.6	......	......	......	....	....	......	....	......	....	....	......	......	......	......	....	......	....
2	95	72	68	0.00	8.6	9.04	1.85	4.9	......	......	......	....	....	35	26	16.0	....	....	7.3	N	......	0.65	0.16	0.033	....
3	93	66	68	0.00	8.4	8.56	1.85	4.6	......	61	52	62	....	46	33	14.3	....	45	6.8	N	4.20	0.54	0.25	0.063	....
4	86	69	68	0.00	8.3	9.14	1.90	4.8	......	......	......	....	....	47	35	14.1	....	....	6.9	N	......	0.76	0.41	0.079	....
5	85	68	68	0.02	8.2	9.37	2.05	4.5	......	......	......	....	....	49	32	19.9	....	48	6.5	N	3.50	1.18	0.46	0.170	....
6	93	67	69	0.00	8.0	9.04	2.00	4.5	......	80	67	94	....	36	35	24.9	....	....	6.0	N	......	1.05	0.61	0.170	....
7	94	70	69	0.00	7.7	9.71	2.05	4.7	......	......	......	....	....	45	33	......	....	44	......	N	4.10	1.16	0.44	0.120	....
8	95	70	69	0.00	8.1	9.16	1.75	5.2	......	76	46	100	....	......	....	......	....	....	......	......	......	......	....	......	....
9	90	75	70	0.00	8.1	9.16	1.85	4.9	......	......	......	....	....	29	27	14.4	....	....	6.3	N	......	0.54	0.14	0.062	....
10	89	65	69	0.09	8.4	8.93	1.95	4.6	......	63	60	213	....	41	33	30.6	....	42	5.9	N	6.18	0.64	0.31	0.077	....
11	91	67	69	0.00	7.8	9.28	1.67	4.0	......	......	......	....	....	30	33	17.1	....	....	6.0	N	......	1.00	0.50	0.120	....
12	75	71	69	0.15	8.3	9.06	1.75	5.2	......	79	64	120	....	53	37	17.0	....	43	6.5	N	4.18	0.96	0.79	0.165	....
13	82	75	70	0.00	8.1	9.13	1.95	4.7	......	......	......	....	....	37	37	16.8	....	....	6.9	N	......	1.08	0.66	0.116	....
14	86	75	70	0.23	8.2	9.11	1.85	4.9	......	70	31	94	....	35	28	......	....	48	......	N	......	1.32	0.76	0.169	....
15	83	67	69	1.69	7.9	9.71	2.05	4.7	......	......	......	....	....	......	....	......	....	....	......	......	......	......	....	......	....
16	88	70	71	0.14	6.1	12.12	2.25	5.4	......	305	55	67	....	34	13	12.7	....	29	7.5	N	5.93	0.37	0.10	0.018	....
17	82	65	72	tr.	5.5	13.20	......	......	......	153	118	....	....	17	14	......	....	10	......	......	......	0.165	0.10	......	....
18	77	65	69	0.00	8.1	9.36	......	......	......	......	......	....	....	25	23	......	....	....	......	N	......	......	....	......	....
19	87	62	69	0.00	7.2	10.88	2.60	4.2	......	127	42	97	....	33	21	11.2	....	43	7.3	N	6.15	0.80	0.27	0.052	....
20	81	64	70	0.00	6.3	12.51	2.80	4.5	......	......	......	....	....	31	23	11.7	....	....	7.0	N	......	0.67	0.26	0.050	....
21	85	64	69	0.00	6.4	12.13	2.70	4.5	......	104	42	17	....	29	25	......	....	45	......	N	3.70	0.24	0.15	0.035	....
22	91	49	69	0.00	7.4	10.6	2.35	4.5	......	......	......	....	....	......	....	......	....	....	......	......	......	......	....	......	....
23	94	58	69	0.00	7.1	9.8	2.25	4.4	......	......	......	....	....	50	34	......	....	....	8.4	N	......	0.98	0.60	0.110	....
24	93	68	68	0.00	8.0	9.6	2.35	4.1	......	140	40	20	....	......	45	......	....	50	6.8	NP	3.10	1.65	0.81	0.150	....
25	93	74	70	0.05	7.8	9.6	2.35	4.1	......	......	......	....	....	66	39	20.0	17	....	5.5	N	2.50	2.20	0.65	0.250	0.16
26	93	75	70	0.04	7.9	9.6	2.25	4.3	......	160	50	25	25	52	42	24.0	19	56	5.5	N	2.20	1.08	0.55	0.140	0.48
27	92	68	70	0.09	8.1	9.4	2.35	4.0	......	......	......	....	....	58	37	21.0	17	....	5.0	N	2.00	0.90	0.42	0.120	0.42
28	92	75	70	0.02	7.8	9.9	2.25	4.4	......	195	35	25	10	70	45	22.0	20	59	4.8	N	2.00	1.40	0.88	0.280	0.47
29	85	61	....	0.01	8.5	8.94	2.25	4.0	5.4	......	......	....	....	......	....	......	....	....	......	......	......	......	....	......	....
30	86	55	....	0.00	8.0	9.74	2.35	4.15	4.9	......	......	....	....	54	34	18.0	15	....	6.8	N	3.70	0.56	0.23	0.060	0.08
31	83	49	....	0.00	8.0	9.56	2.25	4.25	5.0	145	65	35	25	61	44	23.0	20	59	4.7	P	2.50	1.45	0.85	0.170	0.55
Avge.	88	67	69	....	7.8	9.82	2.13	4.50	5.1	126	55	75	20	42.5	32	18.3	18	44	6.4	....	3.70	0.93	0.46	0.115	0.36

NOTE.—*Septic Tanks:* Nos. 4 and 6 in service to Aug. 11th. Aug. 11th, Nos. 4 and 6 put out of service, and Nos. 1 and 5 drained and put into service. Aug. 16th, Nos. 1 and 5 out; Nos. 4 and 6 in; No. 1 partially cleaned out. Aug. 17th, No. 5 thoroughly cleaned out; No. 2 partially cleaned out. Aug. 18th, Nos. 1 and 5 in; Nos. 4 and 6 out. North settling basin put into service Aug. 23d.

seem that during the first few months of operation the test for putrescibility was more rigorously applied than was the case at the testing station and at places elsewhere, thus placing some of the results secured at the Columbus works in a somewhat unfavorable light. Exhaustion of free dissolved oxygen in the undiluted samples of the final effluent in the incubator tests was practically taken as denoting putrescibility, whereas more oxygen could be obtained from the nitrites and nitrates before actual putrefaction would result.

TABLE 17.—RESULTS OBTAINED IN THE EXPERIMENTAL INVESTIGATION WITH TEST SPRINKLING FILTER C.

			Parts per million.
SUSPENDED MATTER	Screened sewage.		209
	Septic effluent.		82
	Filter effluent.		57
OXYGEN CONSUMED	Screened sewage.		51
	Septic effluent.		37
	Filter effluent.		18
NITROGEN	Filter effluent.	As nitrites.	0.69
		As nitrates.	3.10
PUTRESCIBILITY	Filter effluent.	Undiluted.	N.
		1 to 1.	N.
	Final effluent.	Undiluted.	N.
		1 to 1.	N.
			Millions per c.c.
BACTERIA	Screened sewage.		3.6
	Septic effluent.		3.3
	Filter effluent.		1.0

SUMMARY OF COST OF ENGINEERING.

As the design and construction of the water and sewerage work was directed from one office, it has been impossible to apportion exactly to each certain of the items in the cost of engineering, although the figures given are sufficiently close for all practical purposes. A summary of the cost of engineering, however, may be of interest, and is therefore given in Table 18.

TABLE 18.—SUMMARY OF COST OF ENGINEERING.

Work.	Cost of work.	Cost of Engineering.				
		Pay-roll.	Supplies.	Expenses.	Total.	Percentage.
Scioto River Storage Dam and Reservoir	$489 350	$27 540	$3 560	$2 230	$33 330	6.81
Scioto River Pumping Station and Water Purification. Works and work connected therewith	1 237 620	84 340	6 120	5 490	95 950	7.75
Sewage improvements	1 198 180	90 820	6 450	10 280	107 550	8.98
Totals	$2 925 150	$202 700	$16 130	$18 000	$236 830	8.10
Land for Scioto River Storage Dam and Reservoir	$150 850					
Engineering	236 830					
GRAND TOTAL OF COST	$3 312 830					

ENGINEERING ORGANIZATION.

The engineering work was organized as practically a separate branch of the engineering department of the Board of Public Service. At the time the work was started, Julian Griggs, M. Am. Soc. C. E., was the Chief Engineer of the Department, having occupied that position for several years previous to the commencement of this work, and it is a pleasure for the writer to state that the City of Columbus is indebted most to Mr. Griggs for bringing about and carrying forward these two improvements. Mr. Griggs paved the way, and it was due to his foresight and perseverance, in the face of criticism, long since silenced, that the work was successfully started; too much credit cannot be given him. Mr. Griggs was succeeded in 1906 by Mr. Henry Maetzel, who has ably followed the policies of his predecessor. Rudolph Hering and George W. Fuller, Members, Am. Soc. C. E., have acted throughout as Consulting Engineers, and to them great credit is due for their hearty co-operation.

The experimental investigations were ably carried out by George A. Johnson, Assoc. M. Am. Soc. C. E., assisted by William R. Copeland, Assoc. Am. Soc. C. E., Chief Bacteriologist, Mr. A. Elliot Kimberly, Chief Chemist, and Mr. George P. Shute, Assistant Engineer.

Mr. F. B. Edwards was Resident Engineer in charge of the construction of the dam and reservoir; George E. Howe, M. Am. Soc. C. E.,

Resident Engineer in charge of the construction of the Scioto River pumping station, water purification works, and force mains; Mr. Edward A. Kemmler, Resident Engineer in charge of the construction of the sewage pumping stations, purification works, and sewerage work; Mr. Walter W. Jackson, Mechanical Engineer in charge of the mechanical equipment, and Messrs. George E. Howe, and J. William Link, and Arthur J. Decker, Jun. Am. Soc. C. E., in charge of the office work, to whom the successful completion of the work is in no small measure due. The writer was in direct charge of the design and construction of the work, with the titles, successively, of Engineer of Design, Principal Assistant Engineer, and Engineer in Charge.

The operation of the two works has been and is still in charge of Mr. Jackson, as Engineer of Water Supply and Sewage Disposal, assisted by Mr. Copeland, as Chief Chemist and Bacteriologist at the water purification works, and Mr. Clarence B. Hoover, as Chief Chemist and Bacteriologist at the sewage purification works, and to them the credit is due for the successful operation of the works.

In closing, the writer wishes to acknowledge his indebtedness for the hearty co-operation given him, not only by all those connected with the engineering organization, but by the members of the several Boards of Public Service under whose direction the work was done, and the numerous other city officials with whom he came in contact, and who, practically without exception, did everything within their power to further the carrying out of the work.

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PAPERS AND DISCUSSIONS

PRECARIOUS EXPEDIENTS IN ENGINEERING PRACTICE.

By John Hawkesworth, Assoc. M. Am. Soc. C. E.

To be Presented February 16th, 1910.

In presenting this paper for the Society's consideration, the observation may be made that it is not, in the strict sense of the term, a scientific paper. It would seem, however, that if engineers had no thoughts or aspirations in regard to their Profession, other than those applying to technical details, that Profession, and the Society which represents it, would fall short of the standards which inspire workers in other fields. In the many scientific papers which are continually being presented, attention is directed to methods and formulas by which one may build safely and efficiently. With these two watch-words of the Engineering Profession—"safety" and "efficiency"—is it not necessary to class the additional word, "honesty"? In the Engineering Profession, as in other professions, ordinary intentional dishonesty sooner or later brings its own punishment. It is not to such self-evident facts that the writer would draw attention.

There is another kind of dishonesty to which one may, without premeditation, be made accessory, which is known to every engineer and architect, yet very rarely discussed. Possibly this is because some

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

may believe it is the result of the present method of financing large construction work, others that it is caused by undue competition among contractors; and there are a few who pessimistically declare that it is simply a part of the ever-increasing laxity of moral standards in all fields of industry. Whatever the cause, the writer's object is to expose the facts relating to the use of certain precarious expedients, and to hint at a possible remedy. It is hoped that the presentation of this paper to the Society, and not to the public press, will demonstrate that it is not intended as a "muck-raking" article. The evil lies within the circle of knowledge of professional men, by whose efforts alone it can be eradicated.

Let it be assumed that some large piece of work—a public library, a railroad terminal, a hospital, a power-house, or a municipal pumping station—is to be constructed. As either an engineer or an architect may be engaged to take supreme charge of the design and construction, he will be referred to herein as the "designer." The "designer," then, having received his appointment, proceeds with the preparation of his plans. Now, if he be an architect, his specialty will take form in the artistic embellishment and utilitarian arrangement of his design. Rarely will he have, either from his own knowledge or from that of his office force, the qualifications necessary to the economic design of all the other factors, such as structural computation, economic lay-out of heating and lighting, sanitary arrangement of plumbing, and the like. To be sure, some of his assistants, or even he himself, may be able to do one or two of these things as well as specialists, but seldom all of them. If a structural engineer is the "designer," then that feature of the work, and perhaps one or two others, will receive the fullest emphasis, to the possible detriment of the architectural or mechanical side.

Now, occasionally, the "designer" calls to his assistance specialists in each of the departments with which he (or his office force) is unfamiliar. Their fees are usually higher in proportion than that which the "designer" himself is to receive, and must be paid out of his own pocket. Also he or some of his assistants soon acquire that "little learning" which is "a dangerous thing," and begin to believe themselves capable of doing the specialist's work on future occasions. These two reasons militate against this solution of the problem.

Next in order comes the method which the writer believes is used

in the majority of cases, where the work involves a number of radically different specialties. The "designer" prepares his plans and specifications, in complete form as far as his knowledge carries him, tentatively on the points where that knowledge is lacking. Then, whether it be the problem of reinforced concrete design, or heating, or lighting, or what-not, he allows some of the contractors, who have been importuning his office with this very object, to examine his tentative plans and make suggestions for increasing their efficiency and practicability. Of course, there is opportunity here for the ordinary, intentional dishonesty heretofore referred to, such as the insertion in plans and specifications of some privately controlled or patented device, the stone from some particular quarry, or the like. However, it is assumed that the "designer" is not intentionally dishonest, and that he will listen to no suggestions of this kind.

In accepting the services of these contractors, he expressly stipulates that he is thereby placed under no obligation to them, and that he accepts or rejects their recommendations as to changes in the design with precisely the same freedom that he would had he called in consulting experts. The difference consists in the fact that he has not had to pay over a large proportion of his fee.

According to the usual custom, the "designer" receives half his total fee upon completion of the working plans and specifications. This is almost always exhausted by his office expenses up to this point. His profits lie in what is left of the second half of the fee, after deducting his expenses for superintending the actual construction. Should the work not be built, for any reason whatsoever, the "designer" would not receive this second half of his fee. Small wonder, then, that he is reluctant to pay out of his own pocket for specialists, at a time when the ultimate financial outcome to himself is still in doubt.

Returning, now, to the contractors, it is found that in the case of work being planned for private individuals or corporations, they have frequently secured from the owner letters of introduction to the "designer," which cannot be ignored; but, in most cases, those kind-hearted gentlemen, the contractors, carry their competitive methods right up to the point of trying to excel each other in doing the greatest amount of work for nothing. They are ready to furnish samples of brick, stone and mosaic, working models of hardware and plumbing devices, cartoons of ornamental terra-cotta, designs of reinforced con-

crete and ironwork, lay-outs of heating lines or electric wiring, or to pass upon and revise the "designer's" embryonic drawings and specifications on any of these subjects.

Do not let it be forgotten that the "designer" intends to be absolutely honest. He warns these contractors, from whom, on one point or the other, he has accepted advice or assistance, that he will not permit the introduction of exclusively controlled devices, and that the general contract is to be given to the lowest bidder, irrespective of all else. If a municipal job, bids will be advertised for; if a private one, the list of contractors invited to bid will be long enough to render favoritism impossible. Does this discourage the contractor who is giving time and thought, which means money, to the details of his own specialty on the general plans in the "designer's" office? Not in the least; he works hard, constantly changing his lay-out, in whatever line it may be, to suit the general scheme as it evolves from the "designer's" mind. Furthermore, his work and his recommendations are honestly rendered, and about as efficiently as that of the high-priced specialist whom the "designer" might have engaged. Also, the contractor who is allowed to render this assistance never leaves out anything, nor—and this should be well noted—does he call attention to anything superfluous that may exist in the tentative lay-out prepared by the "designer."

Now pass to the time subsequent to the receipt of bids from the general contractors. These bids, which are in each case the aggregation of lowest prices received by the general contractor from various sub-contractors, added to his estimate for that portion of the work which he will do himself, are honestly rendered. The contract for bridge, or library, or power-house, or whatever it may be, is usually awarded to the lowest responsible bidder, who then becomes the general contractor.

For the proper execution and construction of the work, it is usually found necessary to insert in the specification that the general contractor's selection of sub-contractors shall be subject to the approval of the "designer," and, in some cases, of the owner also. The general contractor presents his list of "subs," and on this list are almost certain to be found some of the very men who rendered aid, in one way or another, to the "designer." If for no other reason, they are on the list because their estimates to the general contractor were the lowest

which he had received. Though he be the most honest man in the world, the "designer" cannot help giving his consent to the employment of these sub-contractors, for two legitimate reasons: First, he is reasonably sure of their ability to perform their particular work satisfactorily, or he would have had nothing to do with them in the first place. Secondly, their intimate prior knowledge of the plans and specifications renders it likely that they know the requirements of the job. Another reason is the fact that sometimes the owner may indicate his desire to have these very sub-contractors approved, unless the "designer" can offer definite reasons why they should not be.

As a digression in the effort to ascertain why the owner, whether corporate or municipal, should favor not only the approval of certain sub-contractors, but even urge the "designer" to obtain their cooperation when the plans are being prepared, a single example of each class, taken from actual occurrences, will be given:

A certain large corporation, an insurance company, was erecting a building of enormous size. The structural steel design was a difficult problem, but one well within the "designer's" power. Nevertheless, the president of the company insisted that a certain structural iron contractor should have his engineers check the design. The general contract was awarded, and the list of "subs" was presented to the "designer" for approval. On this list were two structural iron firms, one an independent firm, the other the direct agent of "the trust." The general contractor had noted that the "independent" bid was the lower. The president of the insurance company sent for the "designer," and made him admit that each firm could do the work equally well. Also, it was obvious that, since the general contract was let for a lump sum, the relative cost of the ironwork bids did not enter into the discussion. The designer was directed to approve the iron firm which made the higher estimate, because that firm, "having an intimate knowledge of the plans, showed from its figures that the work could not be done honestly for the price quoted by the independent firm." The "designer" gave his approval, as directed. Of course, the trust behind the higher bidder was financially affiliated with the insurance company, and it is interesting to note that the net cost to the successful firm executing the ironwork was quite a little lower than the bid of the independent. In that case, the general contractor simply paid a rebate unwillingly to the owner, but the "designer" was made the tool of an unfair transaction.

An example of the second class, having to do with municipal ownership, may be cited with equal ease. In many cities, appropriations for public buildings, bridges, and the like, are requested by the superintendent or commissioner having jurisdiction over the department which requires them. Assume that the request is passed upon favorably by a superior board, and goes to a body, such as a Board of Aldermen, for final ratification. This final deciding power, say, has not the right to alter the amount of the appropriation, or the purpose for which it is requested, but it has the privilege of withholding its approval as long as it wishes. If such approval is unreasonably delayed, it may be assumed that the superintendent or commissioner, anxious to gain credit for his administration by carrying out the much-needed work, if for no other reason, seeks to ascertain the cause of delay. He knows a man, who, holding no official position, nevertheless is cognizant of everything in this line. This man suggests that, if the appropriation can be passed, a certain "designer," whom he names, should be appointed. The superintendent or commissioner readily agrees. The "designer" knows nothing of all this, nor is he expected to. His first information comes from the man of no official position, who tells him he has been suggested as "designer" of this great public work.

Now as all governing bodies, whether Boards of Aldermen or not, have a guiding spirit, it may be assumed that the unofficial man obtains the ear of the guiding spirit. The appropriation is quickly passed, and the superintendent or commissioner, free and untrammeled, appoints the "designer" to prepare the plans. The course of events thenceforth is the same as that previously described, and, when the list of sub-contractors comes in, after the general contract has been let to the lowest bidder, the man of no official position is on the spot. Not being connected with the municipality, there is no legal reason why he should not be a stockholder, or on the pay-roll, of some of these sub-contractors who appear on the list. The "designer" not only knows that he owes his appointment to this man, but he may also have a vague suspicion that the work would never have been proceeded with, but for his efforts. What could be more natural, than that, confronted with the names of two sub-contractors of equally good standing, the designer should give his approval to the one suggested by his influential friend?

Should the "designer" feel reluctant about acquiescing in this

matter, though after all it does not benefit him directly in a financial sense, he adopts the following expedient. He gives his approval to two sub-contractors, one of which is the favored firm. The general contractor thereupon beats each down to the bottom price, and then takes steps to find out which is the favored firm by the powers above the "designer." This one he takes care to employ, irrespective of the cost; neither does he fail to emphasize the fact, for it is "bread upon the waters." Discrimination cannot, it is true, be shown in the award of the general contract for municipal structures, but the right to reject all bids is always reserved. By this means, the unpopular or unpolitic general contractor can always be frozen out when his bid happens to be the lowest for the entire work, and he wishes to remain popular, even if it costs a few extra dollars in sub-contracts.

Up to this point, all that has been said shows clearly, or else the purpose of this paper has failed, that the situation of the "designer" is not of his own creation, being forced on him by circumstances, and that he does not profit directly to the extent of a dollar thereby. Also, it should be distinctly remembered, he has done nothing necessarily prejudicial to the safety or efficient construction of the work he has designed.

Somebody, however, must be making an undue or unfair profit. Why do the sub-contractors, and their financial backers, or their silent partner, "the man who holds no official position," do so many kind acts for apparently nothing, or at least for the ordinary contractor's profit only?

It is, of course, reasonable to infer that prior familiarity with the plans of the proposed work gives these sub-contractors a certain advantage in making up their estimates. Having had plenty of time to prepare an accurate statement of cost, they can naturally give a closer figure than their competitors who have, perhaps, had only a few hours to examine the plans and specifications on file in the office of the general contractor; but this advantage is not by any means the only one.

In the description of the preparation of plans and specifications, particular mention was made of the fact that nothing superfluous in design or requirements of construction is ever stricken out. When the opportunity offers, or when the subject happens to be one on which the "designer" is not even fairly well informed, the sub-contractor, in his advisory capacity, can easily insert needless requirements into

drawings and specifications. Should that subject be, for example, heating or plumbing systems, extra lines of piping may be shown, which only an expert in this specialty could with certainty declare needless; or, in the case of the specifications, many requirements as to elaborate testing, or extensive submission of expensive samples, may be inserted, the enforcement of which requirements may or may not be considered essential, depending on who obtains the contract eventually.

Let it now be assumed that the general contract has been awarded, that the sub-contractors, among whom are the favored ones, have been approved, and that the work has been started. Sooner or later the "designer" is informed that certain changes may be made in the plans, or certain requirements of the specifications waived, without detriment to the work. The "designer," being still conscientious, investigates these statements, even calls in other contractors for their advice, and finds that the requests to omit certain things are entirely reasonable. As to the elaborate requirements for testing, samples, and the like, they too are unnecessary, if responsible parties are doing the work. Who could be considered more responsible than those who assisted in its design? The request for their omission or curtailment is granted more or less readily.

At this point it may be remarked that there are two kinds of specifications, the loosely-worded, "blanket" kind, and the one filled with elaborate and detailed requirements as to tests, samples, and so on, both of which offer every opportunity for this kind of discrimination. The first class, the loosely-worded one, clear only on the one point that all power is vested in the "designer," can be interpreted so that the cost of the entire work, or any part thereof, may turn out to be anywhere from one-half the estimated amount to twice that figure. As for the other class of specifications, an impartial examination of the multiplicity of petty, often unnecessary, though always costly, requirements, will show that if enforced down to the last detail, the work could not be performed for twice the contract price. That all will not be enforced is, of course, discounted in the contractor's bid; but only the sub-contractor who is on intimate terms with the "designer," and who has assisted in preparing the lay-out, can be reasonably sure of the omission of these petty and harassing stipulations, as far as his particular work is concerned.

Specifications of this latter class are notoriously frequent. Al-

though they assist his scheme materially, it is not the politic sub-contractor who is responsible for them. They are the result of over-weening vanity on the part of the "designer," who desires to insert therein every requisite and every obligatory condition that he has ever read of or heard about, and whose method of making each specification better and more complete than the last is to keep adding voluminous requirements, without ever weeding out the useless and obsolete clauses evolved during the earlier years of his practice.

Returning now to these requests for omissions. It has been assumed that the "designer" is an honest man. He may, and often does, demand an allowance from the sub-contractor when the request entails, not only less rigid enforcement of the technical clauses of his specifications, but the actual omission of material and work as well. Then the sub-contractor goes to the general contractor and lays the case before him. The latter knows the "pull" possessed by the sub-contractor with the owner, and is glad to assist. The two go over the plans and specifications together in minute detail. Now, it is rare indeed that, in the case of a large piece of construction work, something essential, either in design or specifications has not been inadvertently omitted by the "designer." In the writer's opinion, there has never yet been executed a large contract where there was not something installed, or some work done, which the general contractor could not have legally evaded on the ground that it was not shown or required.

It is to provide against these errors of omission, so certain to occur, that some designers have adopted the "blanket" clause. This is frequently found in the following form:

"Should any items be omitted in the drawings and mentioned in the specifications, or shown on the drawings and not mentioned in the specifications, or neither shown nor mentioned in either the drawings or specifications, but reasonably to be implied, and, in the opinion of the 'designer,' necessary to the complete and satisfactory execution or operation of the work or works, it shall be understood as expressed in both, and shall be carried out as if so expressed, and as directed by the 'designer,' to correspond in all respects with the remainder of the work and works."

Now, it is indeed fortunate for the general contractor that the courts do not interpret such a clause as conveying to the "designer" the all-supreme powers that it appears to. Nevertheless, it furnishes

a basis for tedious litigation, on which the contractor desires to spend neither his time nor his money. The result is usually a compromise.

Having located the items "neither shown nor mentioned," the general contractor goes to the "designer" and makes a counter demand for extra payment. The "designer" is then in a quandary. He knows that if he endeavors to enforce his "blanket" clause, and if the amount involved is sufficiently large, the contractor will fight it. This involves legal expenses and delay in the execution of the work, either of which causes would bring down the wrath of the owners upon the head of the "designer." Neither is he willing, in most cases, to give in entirely, admit his error, and transmit to the owner, with his approval, the contractor's request for an extra payment. To do so would not only render him subject to the accusation of incompetency, and of having prepared an incomplete design, but also, especially in the case of public work, it might be impossible to obtain an additional appropriation.

Thus the "designer" also, is ready for compromise. This is offered by the general contractor, who agrees to do the necessary extra work without charge, if the "designer" will agree to the omission, without allowance therefor, of the unnecessary details, as requested by the particular sub-contractor heretofore mentioned. Here, again, the "designer," if particularly desiring to be honest to the end, may require a statement showing that the value of the work added is equal to that of work omitted. Of course, this is rarely the case, but the statement is always so rendered. The contractor is a better authority than the "designer," on the detailed cost of fractional parts of his work, and the "designer" can do nothing but accept his word for the accuracy of the statement.

This completes the chain. The industrious sub-contractors have not only secured their contracts against all competitors, by knowing how to bid a little lower, but they are actually making a considerably larger percentage of profit than their competitors would have made, even at the higher prices.

There is nothing actually illegal in all this, and engineers and architects of the highest ethical standards are constantly being forced into just such situations. The resultant tendency toward discrimination and the unfair application of specifications cannot help but lower the standards of professional integrity. Graft and dishonest practice are only the next step downward. Such words lose their justly re-

pelling force when the actions which they symbolize become our next-door neighbors. The taint of this corruption is spreading, not only among engineers and architects who are in the position of the "designer," but its baleful influence must of necessity cast its spell over the young engineers employed by many contracting firms, who are thus brought into contact with "the system," and who find their splendid ideals of the old-time engineering standards trailing in the wake of conscienceless competition.

Even though the writer may have succeeded in showing clearly the existence of this unfortunate condition of affairs and its importance to the Engineering Profession, the purpose of this paper would be but half accomplished were there not a possible remedy to be suggested.

When paid on a commission or lump-sum basis, the "designer's" fee is not always sufficient to insure a reasonable profit, over and above his office and running expenses, commensurate with the long years of technical training and experience in subordinate capacities considered so necessary as preparation, before he is entrusted with important work. Bearing in mind those unfruitful years, from a financial point of view, it has become customary for the "designer" to reduce his expenses, and to the same degree increase his profits, by inserting in the contract a clause requiring the contractor to pay the salary of the inspector or inspectors, employed by the "designer," in immediate supervision of the actual construction. These inspectors, however, are directly responsible to the "designer," and are subject only to his authority.

The first step, therefore, is to insure, by agreement between the owner and the "designer," that the fee or charge for professional services shall be properly commensurate, not only with the gross cost of the proposed construction, but also with the difficulties involved.

Secondly, it should be arranged that this charge should be paid in successive installments, in such proportion that four-fifths, and not one-half, of the total amount, should be paid upon completion of working drawings and specifications. This, for reasons heretofore noted, corresponds more closely to the expenses of the "designer" up to this point in the work.

Thirdly, there should be a prior agreement between client and "designer" as to what specialists—such as heating, electrical, or sanitary engineers—are to be employed (if their employment is necessary),

and what fees are to be paid to each. Their fees may come out of the "designer's" own charges, if need be, but the amount should always be pre-determined in his agreement with the owner.

Next in importance comes the question of payment of the field inspectors during construction. It has been seen that this has been required of the contractor, who, of course, figures on the cost thereof in his estimate for the work. Hence the owner pays for it just as surely as though he signed the weekly salary check himself.

It is the writer's opinion that, in the case of men not so honest as the "designer" has been assumed to be, this system is a very fertile field for graft. The "designer" having the absolute right to appoint the inspector and fix his salary, from nothing at all up to the amount specified in the contract, may, by striking a medium between these two figures, save a considerable sum to the general contractor. This saving, or rebate, which really comes out of the owner's pocket, may be applied to various purposes, such as offsetting the contractor's claims for extras due to mistakes or omissions in the design, or to the more frankly grafting one of thereby obtaining the favor of a contractor influential enough to throw more work in the "designer's" way.

All this temptation could be eliminated by having the inspector paid directly by the owner, instead of indirectly, as at present. The salary could be fixed by the prior agreement between owner and "designer," and the selection of the individual could be made subject to the approval of both.

The inspector should also be subject to discharge by either owner or "designer," and his duties should consist in rendering daily reports, in duplicate, to both, showing first, the exact progress of the work to date, and secondly, describing in detail any and all variations from the requirements of plans and specifications. This inspector should not be given power to condemn work. His reports, coming daily under the eyes of the engineer inspectors in the regular employ of the "designer," would enable them to perform judicially all the condemnation necessary by letter, or an occasional visit to the work. The field inspector, however, being constantly on the job, may with propriety warn the contractor when incorrect or improper work is being done, and announce his intention of reporting the same. The contractor must then decide whether or not to persist in the face of such warning.

Then it is essential that all allowances for work omitted, and all extras for additional work done, should be settled by one of the two

following methods: First, as far as possible, the deduction or the extra should be computed on the basis of "unit prices," to be named by the contractor in his bid. Second, when the first is not possible, such amounts should be decided by arbitration between the "designer," the general contractor, and a third party acceptable to both. The valuation should be based on actual cost sheets of the work involved, to which should be added, or from which should be subtracted, a certain fixed percentage representing the contractor's profit. This percentage should be fixed, and be a component part of the contract when it is signed. No extra work should be accepted gratis from the contractor. If such did occur, it would immediately come to the owner's attention through the duplicate reports of the field inspector, and should indicate to him that some kind of reciprocal favoritism was in progress between contractor and "designer."

By the adoption of these safeguards, it would seem that, not only intentional dishonest graft could be prevented, but also the more subtle kind with which the "designer," though profiting nothing directly thereby, is continually being entangled. The remedy here pointed out is not intended to produce a check on the ambition of the "designer," nor does it imply presumptive suspicion of his honesty. On the contrary, it is a true safeguard against a combination of circumstances which would place him in a position, to say the least, unenviable.

There is a secondary advantage to the Profession as a whole, namely, that under the protection here outlined, the work of the "designer" may be judged on its own merits. No longer may it be inferred that the mistakes and omissions of the young "designer" are necessarily the natural result of his inexperience. No longer will the apparent flawlessness of the work of the older "designer" be ascribed to his more mature knowledge, when he shall have become no more amenable to the wily subterfuges of the contractors' system, which, to its own advantage, conceals mistakes. The client or owner will obtain the work for which he has paid. The "designer," without pull or political affiliations, will be on the same basis as the one whose finer sensibilities have become blunted through intimate relations with scheming contractors.

After all, when engineers have written and talked over the technical details of their work, have commented upon and discussed this or that

theory of design or method of construction, does there not remain something even more important in the consideration of those high ideals which should underly all else in the Profession? It is, of course, important that engineers should be true to their work, and to those standards of knowledge and efficiency set by those who have gone before, but is it not equally vital that they should be true to themselves?

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

NORTH RIVER DIVISION.

By Charles M. Jacobs, M. Am. Soc. C. E.*

These observations are written with the purpose of outlining briefly, as far as the writer was concerned, the evolution of the scheme of bringing the Pennsylvania Railroad and the Long Island Railroad into New York City, and also, as Chief Engineer of the North River Division of the New York Tunnel Extension of the Pennsylvania Railroad, to record in a general way some of the leading features of the work on this division, which is that portion of the work extending from the east line of Ninth Avenue, New York City, to the Hackensack Portal on the westerly side of the Palisades, as an introduction to the papers by the Chief Assistant Engineer and the Resident Engineers describing in detail the work as constructed.

It may be stated that, since shortly after the year 1871, when the Pennsylvania Railroad system was extended to New York Harbor through the lease of the New Jersey Lines, the officers of that company have been desirous of reaching New York City by direct rail connection.

The writer's first connection with the tunneling of the North River was early in 1890, when he was consulted by the late Austin Corbin,

* This paper is printed as an introduction to others describing the New York Tunnels and Terminal of the Pennsylvania Railroad, which will appear in the *Proceedings* for February, 1910, and in subsequent numbers.

President of the Long Island Railroad Company and the Philadelphia and Reading Railroad Company, as to the feasibility of connecting the Long Island Railroad with the Philadelphia and Reading Railroad (or with the Central Railroad of New Jersey, which was the New York connection of the Reading) by a tunnel from the foot of Atlantic Avenue, Brooklyn, under the Battery and New York City, and directly across the North River to the terminal of the Central Railroad of New Jersey. Surveys, borings, and thorough investigations were made, and the Metropolitan Underground Railroad Company was incorporated in the State of New York to construct this railroad. Mr. Corbin, however, was aware that, in the transportation problem he had in hand, the Central Railroad of New Jersey and the Philadelphia and Reading Railroad were not as important factors as the Pennsylvania Railroad, and, in consequence, he abandoned the scheme for a tunnel to the Central Railroad of New Jersey for a line direct to the Pennsylvania Railroad terminal in Jersey City.

Meantime, the Pennsylvania Railroad Company, as a result of its investigation of the matter, in June, 1891, thought that the most feasible project seemed to be to build tunnels for rapid transit passenger service from its Jersey City Station to the lower part of New York, connecting there with the rapid transit systems of that city, and also extending under New York on the line of Cortlandt Street, with stations and passenger lifts at the main streets and elevated railroads.

The late A. J. Cassatt, then a Director of the Pennsylvania Railroad Company, and previous thereto as General Manager and Vice-President (and later as President) of that company, was deeply interested in obtaining an entrance into New York City, but was not satisfied with the proposed rapid transit passenger tunnels which required the termination of the Pennsylvania Railroad trains at its Jersey City Station. Therefore, upon his request, in September of the same year, another study and report was made by Joseph T. Richards, M. Am. Soc. C. E., then Engineer of Maintenance of Way of the Pennsylvania Railroad, on a route beginning in New York City at 38th Street and Park Avenue on the high ground of Murray Hill, thence crossing the East River on a bridge, and passing around Brooklyn to Bay Ridge, thence under the Lower Bay or Narrows to Staten Island and across to the mainland, reaching the New York Division of the

Pennsylvania Railroad at some point between Rahway and Metuchen. Mr. Cassatt also had in mind at that time a connection with the New England Railroad, then independent, but now part of the New York, New Haven, and Hartford Railroad system, by means of the Long Island Railroad, and a tunnel under the East River, which in later years, as the result of further consideration of the situation, has been covered by the proposed New York Connecting Railroad with a bridge across the East River and over Ward's and Randall's Islands.

As a result of these investigations, the late George D. Roberts, who was then President of the Pennsylvania Railroad Company, authorized an expenditure of about $25 000 for soundings to determine the nature of the strata for tunneling under water. These soundings were carefully made by Mr. Richards with a diamond drill, bringing up the actual core of all rock found in crossing the waters of New York Bay from the west to the east side and extending from the Narrows to the Jersey City Station of the Pennsylvania Railroad.

After these investigations had been made, early in 1892, Mr. Roberts expressed himself as being favorable to the undertaking, with the definite limitation that the tunnels must be for small cars doing local suburban business, and for the transfer of Pennsylvania Railroad passengers to and from New York, Brooklyn, and Jersey City, and not in any way to be tunnels for standard steam equipment, the expense for terminals and the prohibited use of coal for fuel in such tunnels not warranting any broader consideration. Under such instructions, the interests of the Pennsylvania Railroad Company for effecting a physical entrance into New York City in that year were turned over to Samuel Rea, M. Am. Soc. C. E., then Assistant to the President of that Company, who has been identified with the investigations, and the progress and construction of this work since that time, Mr. Cassatt also working in conjunction with him on the plans then and since considered by the Pennsylvania Railroad Management.

On October 5th, 1892, Mr. Rea, under special direction of President Roberts, made an extended investigation of the various routes which had then been projected for extending the system into New York City by rail or transport, and reported to Mr. Roberts that, in his opinion, because of the limitation of the tunnel scheme to rapid transit trains and the consequent transfer of passengers and traffic carried in passenger trains, and because of the drawbacks caused by the use of steam

locomotives in full-sized tunnels, and the objection to cable traction or any system of transportation which had not then stood the test of years of practical service, the plan of the North River Bridge for reaching New York City and establishing a terminus therein was the best that had been evolved up to that time. The plan provided a direct rail entrance into New York City for all railroads reaching the west side of the Hudson River, and also for the New York Central and Hudson River Railroad, as well as adequate station facilities in that city. This bridge would have had one clear span of 3 100 ft. between pier heads, landing on the New York side at the foot of West 23d Street, and thence the line would have passed diagonally to the terminus at Sixth Avenue and 25th Street. The location of the terminus was subsequently changed to the vicinity of Seventh Avenue and 36th Street. The bridge was designed with three decks: The first or lower deck was to accommodate eight steam railroad tracks; the second was to have six tracks, four of which could be assigned for rapid transit trains operating with electric power, and the other two for steam railroad trains; the third deck, reached by elevators, was to be a promenade extending from anchorage to anchorage. A connection with the Eleventh Avenue tracks of the New York Central and Hudson River Railroad was to bring the trains of that road into the Union Station. The Bridge Company had a Federal charter—granted in 1888—with broad powers. Gustav Lindenthal, M. Am. Soc. C. E., was Chief Engineer, and he and Mr. Rea were corporators and among its early promoters. The Pennsylvania Railroad Management looked with favor on its construction at that time, as subaqueous tunnels, with standard railroad equipment with steam traction, were not regarded as a final or attractive solution of the problem, from the standpoint of the Management, and at a subsequent period the Pennsylvania Railroad Company agreed to use the North River Bridge provided the other roads reaching the west bank of the Hudson River would join. These roads, however, did not avail themselves of the opportunity which in its broadest scope was laid before them in 1900, after the Board of Directors of the Pennsylvania Railroad Company had approved the scheme at the instance of Mr. Cassatt.

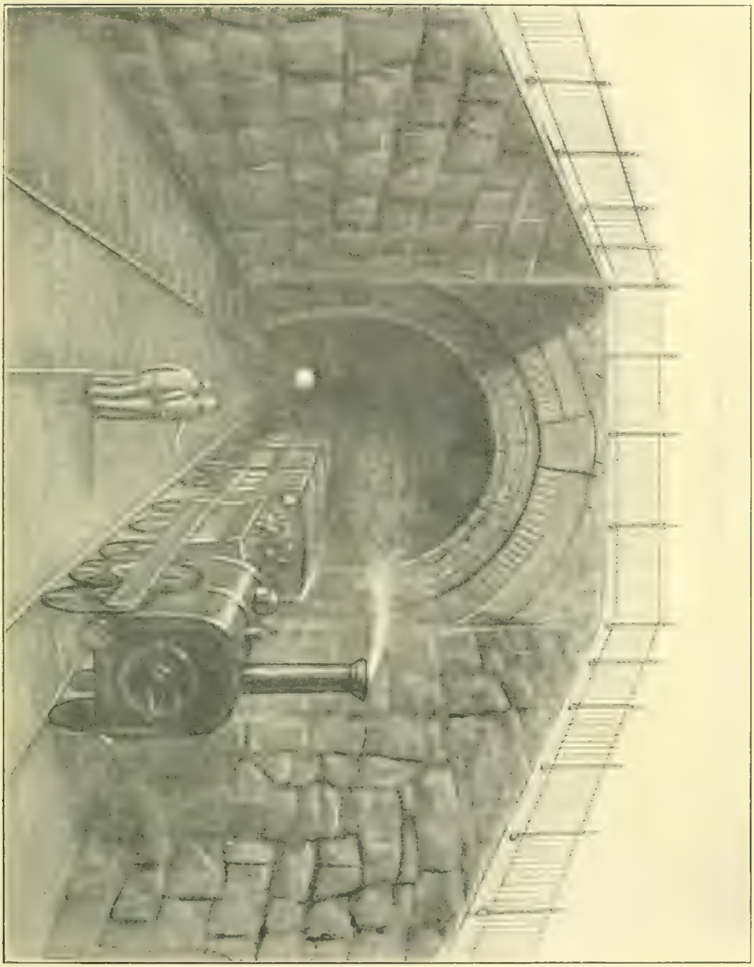
The scheme of Mr. Corbin for a subway connection, between Flatbush Avenue and the Jersey City Station of the Pennsylvania Railroad, for local transit, took form in 1892, and, jointly with the

Pennsylvania interests, railroad companies were incorporated in the respective States to build a tunnel from under the Jersey City Station, under the Hudson River to Cortlandt Street, New York City, thence under Maiden Lane, the East River, and Pineapple and Fulton Streets, Brooklyn, to a location at or near Flatbush and Atlantic Avenues. On May 9th, 1893, these companies were merged into the Brooklyn, New York, and Jersey City Terminal Railroad Company, and estimates and reports on the construction were made ready by the writer in association with Mr. Rea, pending application for the franchises. The panic of 1893, occurring about that time, checked further progress on this scheme, and, before it could be revived again, other important projects for reaching New York City were given consideration.

That part of Mr. Corbin's plan contemplating a subway under Atlantic Avenue in Brooklyn to the present Flatbush Avenue Terminal was not a new idea, as a tunnel had been built in 1845 and operated under a portion of Atlantic Avenue, but later it was filled up. Plate XXVIII, reproduced from a crayon sketch which was the property of the late William H. Baldwin, Jr., is a view of this tunnel.

In conjunction with schemes for river tunnels, complete plans for rapid transit subways for New York City, very much on the line of the present rapid transit subways, were also prepared for Mr. Corbin by the writer. These plans provided a system of deep tunnels in rock, entirely below the plane of quicksand, and at the Battery the lines were to connect directly into the tunnels to Long Island and New Jersey, respectively, and the stations throughout, where the rock was at a deep level, were to be fitted with elevators, grouped as suggested in Plate XXIX, using private property on each side of the street at station locations—one side for north-bound and the other side for south-bound traffic. These plans were submitted to the first Rapid Transit Commission, and, after long consideration, were rejected by that Commission because they provided for the construction of the tunnels by a private company, notwithstanding Mr. Corbin gave the Commission assurances of ample financial means to carry the work to completion.

During the years 1892-93 Mr. Corbin was convinced that it was necessary to get better facilities for handling the baggage and express matter of the Long Island Railroad and the Long Island Express Company across the East River between Long Island City and New York



TUNNEL UNDER PART OF ATLANTIC AVENUE, BROOKLYN.
(From a Crayon Sketch.)

City, and he instructed the writer to investigate and report on the feasibility of building a tunnel, along the lines of the East River Gas Tunnels, then nearly completed, between the foot of East 34th Street, New York City, and the Long Island City Station of the Long Island Railroad. In 1893 an investigation was made for such a tunnel, to be of similar size to the East River Gas Tunnel (8 by 10 ft.), solely for the purpose of handling baggage and express matter. Investigation was made and estimates prepared, but the cost was considered to be prohibitive in view of the possible earnings solely from the handling of baggage and express, and the matter was not considered further.

While Mr. Corbin was deeply interested in the down-town river tunnels, the up-town situation was of great importance to the Long Island Railroad, and, having allied himself with Mr. Charles Pratt, they took up generally the franchise owned by Dr. Thomas Rainey for a bridge over Blackwell's Island. Mr. Corbin became interested with Dr. Rainey in 1894, and the actual construction proceeded on this bridge. The design provided for four railroad tracks, besides highways for tracks, pedestrians, etc., with a terminal station at Third Avenue and 64th Street, New York City, which, under the franchise, was the limit to which the railroad could proceed.

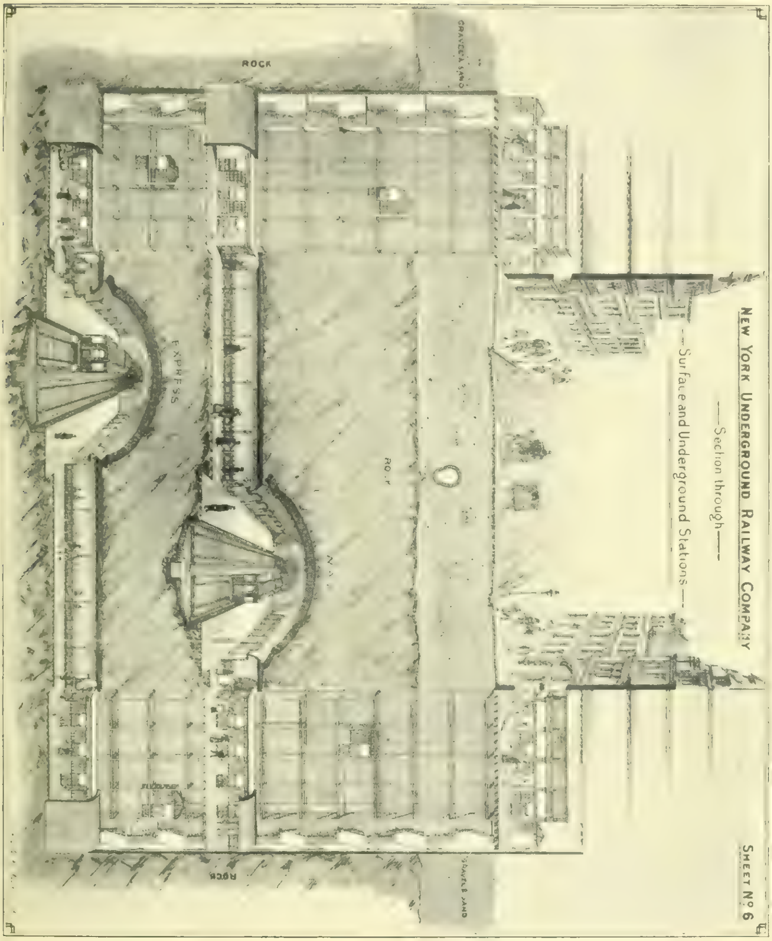
At this period there were two projects for bridging the Hudson or North River: the New York and New Jersey Bridge Company at about 59th Street, and the North River Bridge Company at 23d Street, as hereinbefore described. Several studies were made by the writer, with the idea of making a rail connection between the Long Island "Rainey" bridge and a bridge over the North River. An overhead structure connection was prohibitory, as no franchise could be obtained to cross Fifth Avenue with an overhead structure. Sketches were prepared for a subway construction to connect with the bridges, but a final plan was not worked out.

The failure to carry out the joint undertaking with the Pennsylvania Railroad Company in 1893 led Mr. Corbin to revive the scheme of extending the Long Island Railroad from Flatbush Avenue, Brooklyn, to New York City, therefore consideration was given to a relocation of the route for Mr. Corbin during the early months of 1896, the idea being that the entire up-town outlet for the Long Island Railroad would be by Blackwell's Island Bridge, and the tunnel project would give the down-town outlet.

At this time a commission had been appointed by the Legislature to investigate the conditions on Atlantic Avenue, Brooklyn, and evolve some scheme for the elimination of grade crossings on that avenue. Early in 1896 plans were prepared and presented to this Commission; first, for a subway from Flatbush Avenue Terminal for the entire distance to the limits of the City of Brooklyn at Eldert's Lane; second, for a subway from the Flatbush Avenue Terminal to East New York, Manhattan Crossing, the railroad to remain as it previously existed at grade through the 26th Ward of Brooklyn. Each of these schemes contemplated an extension through Brooklyn to New York City at Cortlandt Street and Broadway, and surveys and borings for this work were made across the East River. In the summer of 1896, on the decease of Mr. Corbin, all projects and work were immediately stopped; but, after some months, Mr. W. H. Baldwin, Jr., when elected President of the Long Island Railroad Company, took up actively the reconsideration of the means whereby the Long Island Railroad could reach New York City. After the fullest consideration, he decided that the Blackwell's Island Bridge was by no means a suitable, adequate, or convenient entry for the Long Island Railroad into New York City, as it involved too great a cost and altogether too rigid a connection; it was also a very inconvenient location, inasmuch as it was cut off from convenient access to the west side of New York City by Central Park.

For the down-town connection, Mr. Baldwin became enthusiastic, but he had in mind, throughout, the all-important necessity for the Long Island Railroad to reach the Pennsylvania Railroad across the North River. At the same time Mr. Baldwin took up energetically the Atlantic Avenue Improvement with the Atlantic Avenue Commission, and, on consideration, decided it was essential that it should extend through the 26th Ward above or below grade. The better plan, of course, was obviously to make it a subway throughout, but, further, the residents of this ward objected to the subway through that section, and that construction would have made any change of the Manhattan Beach Division at Manhattan Crossing very difficult for the future; besides this, the controlling factor was the absolute limitation by the City of Brooklyn of the amount of expenditure therefor in which they would participate, therefore a composite scheme, which is the plan as carried out, was agreed upon, being in part subway and part elevated. This scheme reached a focus

PLATE XXIX.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
JACOBS ON
NORTH RIVER DIVISION: PENNSYLVANIA RAILROAD.



early in 1897, and the law constituting the Board for the Atlantic Avenue Improvement was passed, with a provision in the last paragraph of the Act, for the construction of a tunnel from Flatbush Avenue Terminal under Flatbush Avenue and Fulton Street to Pineapple Street, crossing the river to Broadway and Maiden Lane (Cortlandt Street), New York City, and with the understanding that it would be extended beyond the New York State Line to the Pennsylvania Railroad Station in New Jersey. This gave the legal right for the construction of this tunnel, and, on June 20th, 1899, the New York and Long Island Terminal Railroad Company was incorporated for the purpose, Mr. Baldwin being President and J. V. Davies, M. Am. Soc. C. E., Chief Engineer. Application was immediately made to the Boards of Aldermen of Brooklyn and of New York City. The latter acted favorably on the application, but the Board of Aldermen of Brooklyn held the matter up, while the Rapid Transit Commission laid out and promulgated the plan for Contract No. 2 of the Rapid Transit Subway. With the understanding that the Rapid Transit Brooklyn extension would be constructed to the Flatbush Avenue Terminal, Mr. Baldwin withdrew the application for the independent franchise, and agreed to proceed with the Atlantic Avenue Improvement, on the basis of the City proceeding with the Brooklyn extension of the Rapid Transit Subway. This provided for the Long Island Railroad entry down town.

Subsequently, however, it was proved that Mr. Baldwin had not been fully satisfied that this was the proper solution of the matter, for on April 12th, 1901, and upon his recommendation, the Board of Directors of the Long Island Railroad Company took over from the Pennsylvania Railroad Company its entire interests in the old Brooklyn, New York, and Jersey City Terminal Railway Company, thus giving him control of the route from Flatbush Avenue *via* Maiden Lane and Cortlandt Street to underneath the Jersey City station.

In the early part of 1900 active consideration was being given by the Pennsylvania Railroad and other railroads terminating in New Jersey to the proposed North River Bridge, as hereinbefore stated, and, for the Long Island Railroad, Mr. Baldwin organized a new company to construct a tunnel from the Long Island Railroad at Sunnyside Yard, diving under the streets of Long Island City by two tracks under the East River to the foot of 33d Street and

then proceeding under 33d Street as far as Seventh Avenue. A station was to be located at Fourth Avenue below the Rapid Transit Subway Station and also a large Terminal Station at Broadway. For this purpose an option was obtained on the property of the Newbold Lawrence Estate, at Broadway, Sixth Avenue, 33d and 34th Streets, now occupied by Saks' Store. Mr. Baldwin, however, considered that the amount of the investment ($1 600 000) for that property was too great for this purpose, and allowed the option to expire. The property was sold within a week thereafter to the Morganthau Syndicate for $2 000 000. At this time (May, 1900), the Pennsylvania Railroad obtained a controlling interest in the Long Island Railroad, and thereafter the two schemes became one. Mr. Baldwin and Mr. Rea purchased two 25-ft. lots on 33d Street just east of Broadway for an entrance to the underground station. Plans were also prepared for extending this line from Seventh Avenue northward under Seventh Avenue to 45th Street. The investigation and preliminary work in connection with this project were carried out in the early part of 1900.

Reconsideration was given by Mr. Baldwin to the proposed location of the up-town tunnels, with the idea of connecting the New York Central and Hudson River Railroad by a tunnel between Long Island City (Long Island Railroad Station) and the foot of 42d Street and extending to the Grand Central Station, but nothing further than investigation and the preparation of estimates was done on this.

In the summer of 1901 Mr. Cassatt was in Paris and was advised by Mr. Rea of the opening of the extension of the Orleans Railway to the Quai d'Orsay Station and its successful operation by electric power, also of the possibility of the Pennsylvania Railroad reaching New York City in a similar way (the other trunk lines not having joined in the promotion of the North River Bridge project). He at once examined the new line, and then consulted the writer in London in relation to the possibility of building tunnels under the North River. The writer returned to New York with Mr. Cassatt, and soon thereafter a conference of Mr. Cassatt, Mr. Rea, and Mr. Baldwin with the writer and Mr. Davies was held in the Pennsylvania Railroad Company Office in New York, when Mr. Cassatt outlined the scheme practically as it is now carried out, the only difference being that he also proposed a station on property of the New York and Harlem Railroad Company at 33d Street, which was soon abandoned on account of the grade from

the East River, and particularly because of the superior location of the adopted site at Seventh Avenue and 33d Street, this being central between the down-town commercial and financial district and Central Park, which divides New York City. On Mr. Cassatt's instructions, surveys and investigations were begun in November, 1901, and estimates, drawings, etc., were made. Preliminary estimates were presented to him on November 8th, 1901. Following this, borings were continued, and a plan was presented to Mr. Cassatt for assisting the support of the North River tunnels on piles, if necessary. At the time of the appointment of the Board of Engineers and the general organization of the work, the preliminary investigations and work had been carried to an advanced state.

One result of the determination of the Pennsylvania Railroad Company to extend its lines into New York City and thus move its principal station from Jersey City, was that the down-town local and suburban as well as through business was not provided for properly. Mr. William G. McAdoo, appreciating this opportunity, revived the scheme of an electric subway from Jersey City to New York, originally promoted by Mr. Corbin and associates, but not including the extension *via* Maiden Lane to Brooklyn, and entered into negotiations with the Pennsylvania Railroad Company to provide for this down-town business by extensions of the tunnel lines of the New York and New Jersey Railroads to Exchange Place, Jersey City, under the Pennsylvania Railroad Station, and thence across the Hudson River to Cortlandt and Church Streets. As a result, the Hudson and Manhattan Railroad Company was organized in 1902, and contracts were made with the Pennsylvania Railroad Company for the sub-surface use of its station in Jersey City, and for the interchange of passenger business at that point between the trains of the Pennsylvania Railroad Company and the tunnel of the Hudson and Manhattan Railroad Company. Later, a further contract was made with the Pennsylvania Railroad Company providing for the construction of the tunnel of the Hudson and Manhattan Railroad Company westward under the tracks of the Pennsylvania Railroad in Jersey City to a junction with the latter at Summit Avenue, at which point can be installed a joint station, and the operation effected of a joint electric train service between Church Street, New York City, and Newark, N. J., the Pennsylvania Railroad tracks between Summit Avenue and Newark to be electrified

for that purpose, with a transfer station established east of Newark, at Harrison, at which point the steam and electric locomotives will exchange. By means of this, all down-town passengers will transfer to the electric service at Harrison Station, and thus the Pennsylvania Railroad Company is expected to be relieved of maintaining a separate steam service for passenger traffic to Jersey City and a large down-town station with extensive contingent facilities at that point.

From the foregoing it will be seen that the final decision to extend the Pennsylvania Railroad into and through New York City by a system of tunnels, and erect a large station in that city on a most eligible site, was not reached in a hurried or off-hand manner, but after years of painstaking study and a full and extended investigation of all routes, projects, and schemes, whether originating with the company or suggested by others.

Plate XXX is a map of New York City and vicinity on which are shown the various lines contemplated in the evolution of the New York Tunnel Extension of the Pennsylvania Railroad hereinbefore outlined.

The question of tunnels under the North River was an uncertain factor in the larger Pennsylvania Railroad scheme, owing to the nature of the ground composing the river bed in which the tunnels would be constructed.

It is well known that about 35 years ago an attempt was made to construct a tunnel under the North River by using a "Pilot" system under compressed air and forming the tunnels in brick masonry. Owing to the very soft nature of the materials through which it passed, several serious accidents occurred, and the work was abandoned after about 2 000 ft. of tunnel had been constructed. Later, this work was taken up again, when a shield was installed and an additional 1 800 ft. was built with cast-iron segmental lining, but the work was again abandoned, owing principally to financial difficulties while coincidentally before entering a rock reef which presented another serious difficulty in construction. The experience then in the construction of this tunnel led capitalists and engineers to believe that, owing to the very soft nature of the ground, a tunnel could not be built that would be sufficiently stable to withstand the vibration due to heavy traffic, and for this reason tunnels under the North River were not looked upon as practicable. The writer devised a scheme to carry within the tunnel the rolling loads on bridging supported on piers or piles extend-

PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD

PENNSYLVANIA RAILROAD TUNNELS
NORTH RIVER DIVISION

ENGINEERING STAFF ORGANIZATION

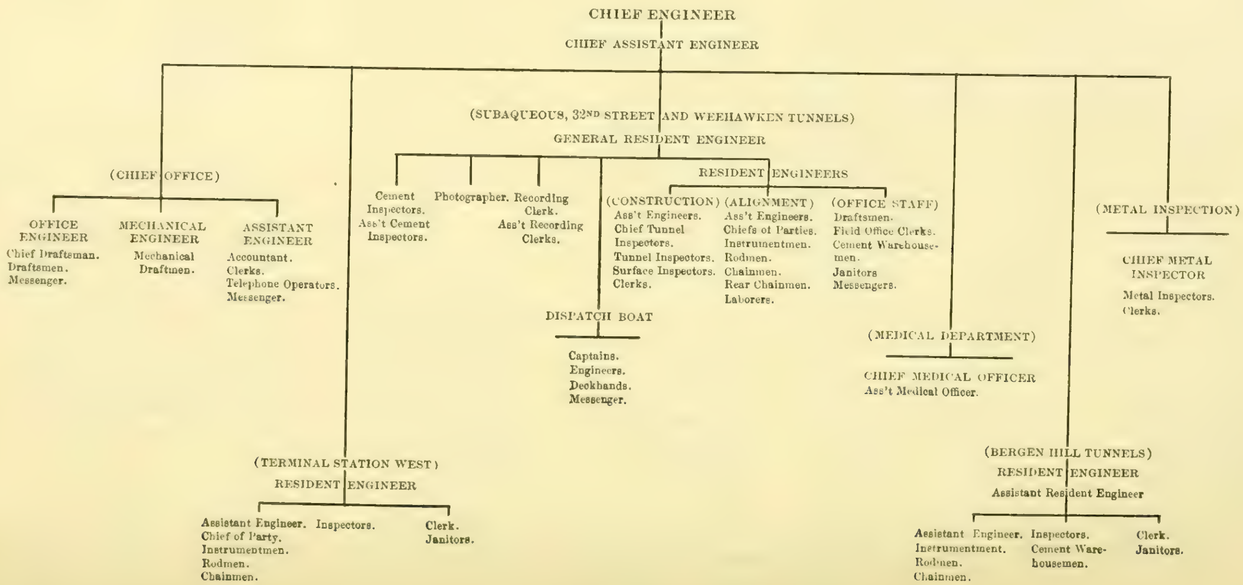


FIG. 1.

ing from the tunnel invert down to hard material. These would be attached to the tunnel itself or would pass into it independently through sliding joints in the tunnel shell. This scheme gained the confidence of the management, as it was believed that, by adopting such a plan, tunnels could be built in the soft material underlying the Hudson River and remain stable under all conditions of traffic. After thus feeling assured that by this method the tunnels could be made safe beyond question, orders were given to proceed with the great work of the extension into New York of the Pennsylvania and Long Island Railroad systems.

The organization of the engineering staff is shown on the diagram, Fig. 1. In the beginning of 1902 and during the period of making studies, additional borings, and preliminary triangulations, and prior to making the contract plans and specifications, James Forgie, M. Am. Soc. C. E., was appointed Chief Assistant Engineer by the writer. To him all the Resident Engineers and other heads of the Engineering Departments reported.

The work was divided into three Residencies:

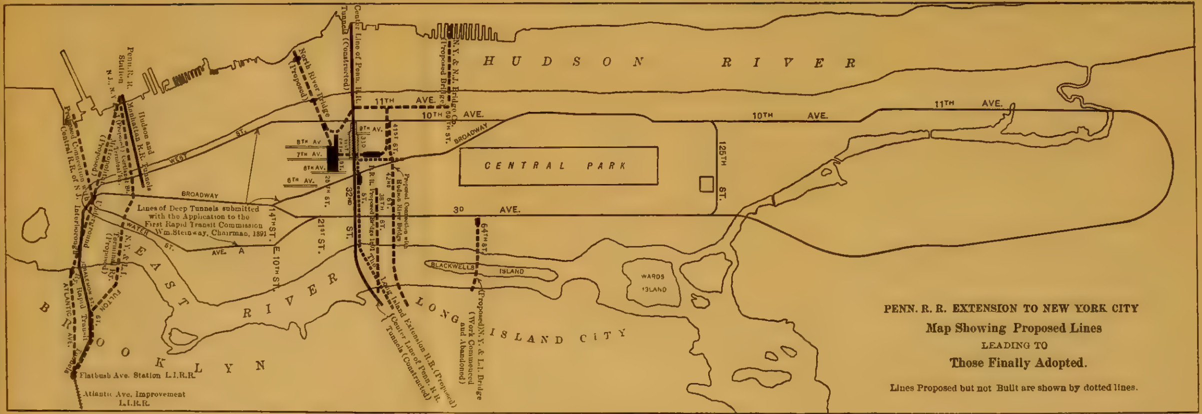
1.—The Terminal Station-West, under the charge of B. F. Cresson, Jr., M. Am. Soc. C. E., Resident Engineer, comprising the work from the east side of Ninth Avenue to the east side of Tenth Avenue, including excavation, retaining and face walls, and the extensive work of underpinning Ninth Avenue with its surface and elevated railroads and other structures.

2.—The River Tunnels, under the charge of B. H. M. Hewett, M. Am. Soc. C. E., General Resident Engineer, and Mr. H. F. D. Burke and William Lowe Brown, M. Am. Soc. C. E., Resident Engineers, including the land tunnels from the east side of Tenth Avenue, New York City, to the commencement of the iron-lined tunnels, and extending westward from there to the Weehawken Shaft, New Jersey.

3.—The Bergen Hill Tunnels, under the charge of F. Lavis, M. Am. Soc. C. E., Resident Engineer, including the rock tunnels from the Weehawken Shaft to the Hackensack Portal on the west side of the Palisades, all in New Jersey.

Paul A. Seurot, M. Am. Soc. C. E., acted as Office Engineer in charge of the drawing office, and Mr. J. Soderberg as Mechanical Engineer in charge of the mechanical drafting. Prior to the construction of the above works Mr. C. J. Crowley acted as Resident Engineer on

PLATE XXX.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
JACOBS ON
NORTH RIVER DIVISION: PENNSYLVANIA RAILROAD.



PENN. R. R. EXTENSION TO NEW YORK CITY
Map Showing Proposed Lines
LEADING TO
Those Finally Adopted.

Lines Proposed but not Built are shown by dotted lines.

the construction of the Weehawken Shaft, and J. F. Rodenbough, Assoc. M. Am. Soc. C. E., on that of the Manhattan Shaft.

Table 1 shows the quantities of certain materials and other statistics regarding this Division.

TABLE 1.

	Bergen Hill.	River Tunnels.	Term. Sta.-W.
Excavation disposed of (or displaced), in cubic yards...	263 000	238 995	517 000
Cast metal used in tunnel, including cast iron and cast steel, in tons	....	64 265	....
Steel bolts used, in tons	....	2 606	....
Cement used (concrete and grout), in barrels	95 000	145 500	33 000
Concrete, in cubic yards	95 000	75 400	18 500
Dynamite for blasting, in pounds	600 000	100 400	206 000
Brickwork, in cubic yards	....	4 980	....
Structural steel (including Pier 72), in pounds	50 000	3 141 000	1 475 000

The number of passengers carried on the Elevated Railroad and surface lines of Ninth Avenue during the underpinning of these structures was about 125 000 000.

The Board of Engineers, organized by the Pennsylvania Railroad Company in January, 1902, immediately took up the matter of route and grade. The center line, which had been assumed as the center line of 32d Street extended westward, was slightly changed.

The grade adopted was approximately 2% descending westward from Ninth Avenue, which would place the tunnel well below the Government dredging plane of 40 ft. below mean low water at the pier head line; thence westward on a lighter grade still descending until the deepest portion of the river was reached where the top of the rail would be about 90 ft. below mean high water, this location giving sufficient cover over the tunnels to insure stability and guard against the possibility of shipwrecks settling on the tunnels. From this point to the portal an ascending grade of 1.30% was adopted, which gave the lines sufficient elevation to cross over the tracks of the New York, Susquehanna and Western and the Erie Railroads, which run along the westerly base of the Palisades. Owing to the exigencies of construction, these grades in the river were very slightly modified. Plate XXXI is a plan and profile of the tunnels as constructed.

The Board of Engineers early in 1902 took up the question of supports for the tunnels under the North River, and various plans and

schemes were considered. It was finally decided to support the tracks on screw-piles carried through the lining of the tunnels, as originally proposed by the writer.

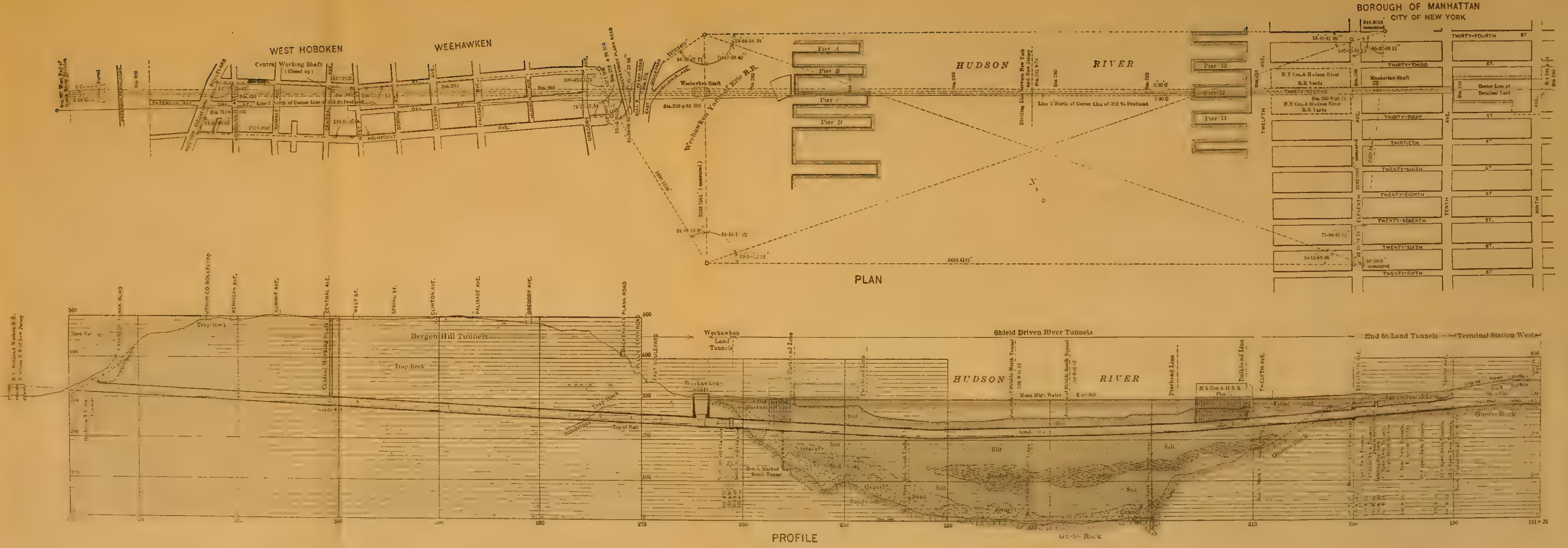
In order to know something of the capacity of screw-piles in the actual material to be passed through, it was resolved to test them. A caisson was sunk at the end of one of the Erie Railroad piers on the New Jersey side near the line of the tunnels, and, to obtain parallel conditions as much as possible, the excavation was carried down to the proposed grade of the tunnel. Various types of screw-piles were sunk therein and tests were made, not only of the dead load carrying capacity, but also with the addition of impact, when it was found that screw-piles could be sunk to hard ground and carry the required load. The final part of the test was the loading. The screw-pile, having a shaft 30 in. in diameter and a blade 5 ft. in diameter, was loaded with 600 000 lb., with the result that, for a month—the duration of this loaded test—there was no subsidence.

Again, and after the iron tunnel lining had been constructed across the river, tests were made of two types of supports: One a screw-pile 29½ in. in diameter with a blade 4 ft. 8 in. in diameter and the other a wrought-iron pipe 16 in. in external diameter. Tests were made, not only for their carrying capacity, but also for their value as anchorages, and it was found that the screw-pile was more satisfactory in every way; it could be put down much more rapidly, it was more easily maintained in a vertical position, and it could carry satisfactorily any load which could be placed on it as a support for the track. The 16-in. pipe did not prove efficient either as a carrier or as an anchorage. These tests will be mentioned in the detailed description of the work to follow. Figs. 2 and 3 illustrate the general arrangement and details of the machine designed by the writer and used for sinking the test piles in the tunnels. This machine had been used originally on the New Jersey side on the test pile at Pier C, and the adaption was not exactly as shown on these drawings, but if the screw-piles had been placed in the tunnels, the arrangement shown would have been used.

Surveys, soundings, and borings were commenced in the latter part of 1901 on an assumed center line of tunnels which was the center line of 32d Street extended westward.

The soundings were made from a float stage fastened to a tugboat, the location being determined by transits on shore and the elevation

PLATE XXXI.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
JACOBS ON
NORTH RIVER DIVISION: PENNSYLVANIA RAILROAD.



by measuring from the surface of the water, a tide gauge being continually observed and the time of soundings and gauge readings kept.

In the river wash-borings were made from a floating pile-driver on which was installed a diamond-drill outfit of rods, pump, etc. Fourteen borings were completed in the river. Considerable difficulty was found in holding the pile-driver against the current, the material in the bottom being very soft, and several borings were lost owing to the drifting of the pile-driver. Each boring was continued, and the depth of several was more than 250 ft. below the surface of the water. The borings on land were mostly core borings, and were generally made with the chilled shot boring machine.

Base lines, about 2 250 ft. in length, were measured on each side of the river, and observation points established. It was necessary to build a triangulation tower 60 ft. high on the New Jersey side as an observation point. The base lines were measured with 100-ft. steel tapes which were tested repeatedly, and the work was done at night in order to obtain the benefit of uniform temperature and freedom from traffic interruptions. From the base line on the New Jersey side, which passed over the Weehawken Shaft, an elevated point on the assumed center line on the side of Bergen Hill was triangulated to, and from this point westward a closed polygon was measured along the streets to the top of the hill on the west side and thence along the assumed center line to the portal. The level transfer across the river was made by sighting across in opposite directions simultaneously, and also by tide gauges. The outline of the final triangulation system is shown on Plate XXIX.

The decision as to the locations of the shafts on both sides of the river, for construction purposes and finally for permanent use, was a comparatively simple matter, and, all circumstances considered, they are unquestionably in the most suitable places. On the New York side the shaft was as near as practicable to the line dividing the subaqueous iron-lined tunnels from the land tunnels, and on the New Jersey side the shaft was placed centrally on the line of the tunnels and on the nearest available ground to the river, while at the same time beyond the other end of the river tunnels, thus necessitating driving the subaqueous tunnels only from east and west to meet under the river. A caisson shaft on the New York side, on the line of the tunnels near the river bulkhead, was at one time considered, but was not

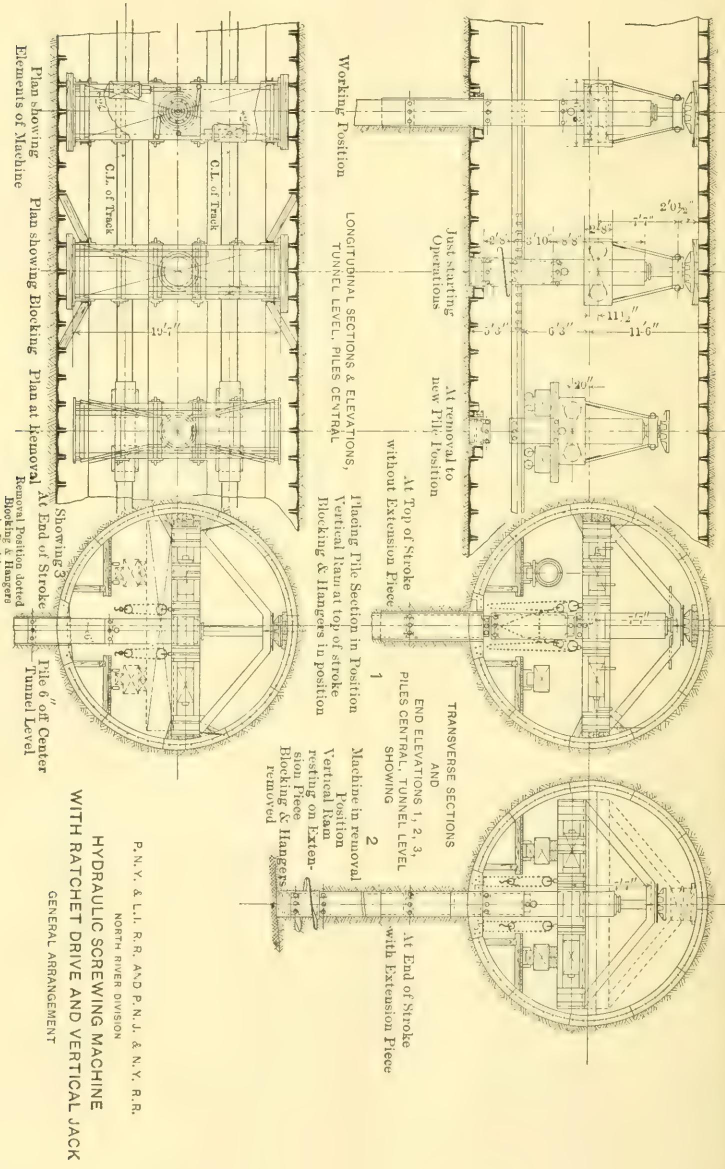

Working Position
Just starting Operations
At removal to new Pile Position
At Top of Stroke without Extension Piece
LONGITUDINAL SECTIONS & ELEVATIONS, TUNNEL LEVEL, PILES CENTRAL
C.L. of Track
Plan showing Elements of Machine
Plan showing Blocking
Plan at Removal Showing 3
Removal Position dotted Blocking & Hangers in Position
At End of Stroke
Pile 6" off Center Tunnel Level
Placing Pile Section in Position Vertical Ram at top of stroke Blocking & Hangers in position
1
TRANSVERSE SECTIONS AND END ELEVATIONS 1, 2, 3, PILES CENTRAL, TUNNEL LEVEL SHOWING
Machine in removal Position Vertical Ram resting on Extension Piece Blocking & Hangers removed
2
At End of Stroke with Extension Piece
P. N. Y. & L. I. R. R. AND P. N. J. & N. Y. R. R.
NORTH RIVER DIVISION
HYDRAULIC SCREWING MACHINE WITH RATCHET DRIVE AND VERTICAL JACK
GENERAL ARRANGEMENT

FIG. 2.

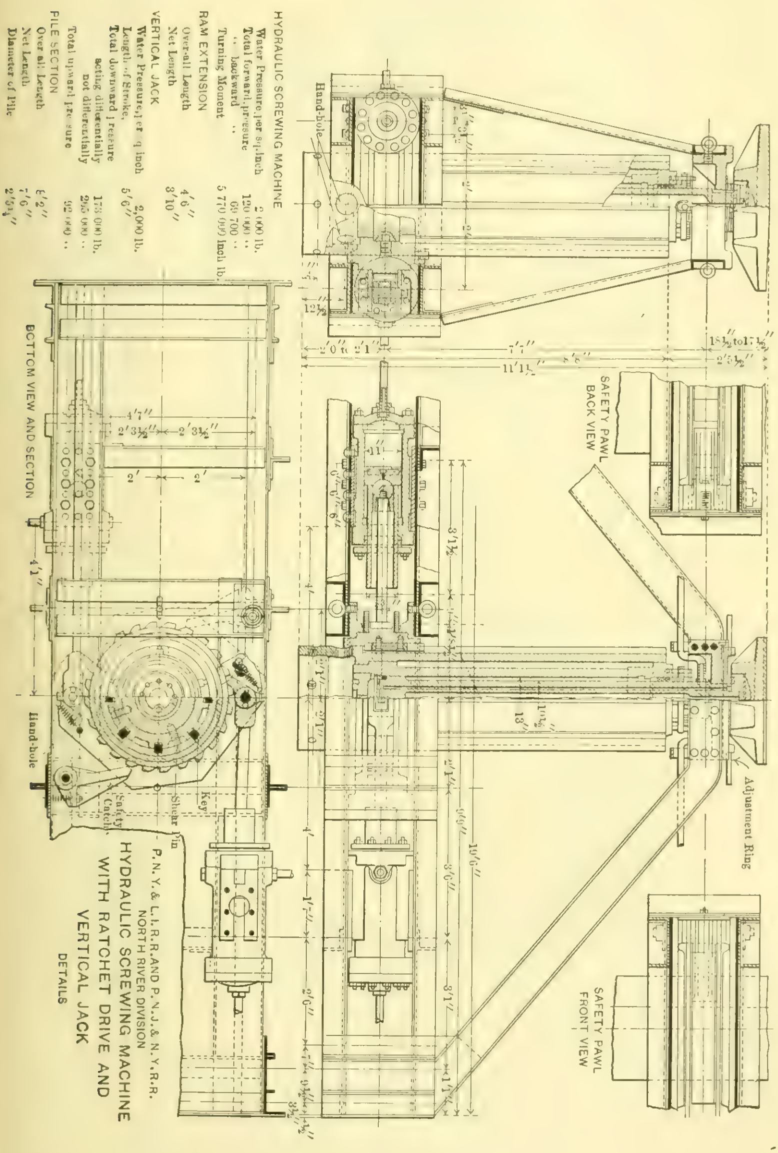

HYDRAULIC SCREWING MACHINE
Water Pressure, per sq. inch 2 000 lb.
Total forward pressure 120 000 ::
" backward " 60 700 ::
Turning Moment 5 770 000 inch lb.
RAM EXTENSION
Over-all Length 4'6"
Net Length 3'10"
VERTICAL JACK
Water Pressure, per sq. inch 2,000 lb.
Length of Stroke, 5'6"
Total downward pressure
acting differentially 175 000 lb.
not differentially 265 000 ::
Total upward pressure 92 000 ::
PILE SECTION
Over-all Length 8'2"
Net Length 7'6"
Diameter of Pile 2'0¼"
Hand-hole
SAFETY PAWL BACK VIEW
SAFETY PAWL FRONT VIEW
Adjustment Ring
BOTTOM VIEW AND SECTION
Key
Shear pin
Safety Catch
P.N.Y.& L.I.R.R. AND P.N.J.& N.Y.R.R.
NORTH RIVER DIVISION
HYDRAULIC SCREWING MACHINE
WITH RATCHET DRIVE AND
VERTICAL JACK
DETAILS

FIG. 3.

adopted as it entailed the driving of two shields both east and west, in addition to the two from New Jersey, adding to the plant outlay while not affording any material saving in the time of construction.

It was thought desirable to construct the shafts on the two sides of the river in advance of letting the main contracts for the tunnels. The Manhattan Shaft is north of the line of the tunnels, on the north side of 32d Street, east of Eleventh Avenue. The Weehawken Shaft is on the line of the tunnels in the yards of the Erie Railroad on the New Jersey side, and the distance between the shafts is about 6 575 ft. The contracts for these shafts were let in June, 1903, to the United Engineering and Contracting Company, and they were completed and ready for use at the time of letting the main contract for the tunnels, thus saving considerable time.

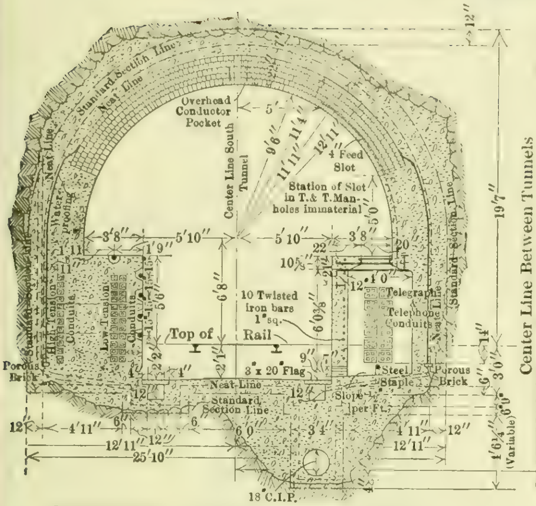
The Terminal Station-West.—Between Ninth and Tenth Avenues. —In the original design it was contemplated to have a four-track tunnel under 32d Street from Ninth to Eleventh Avenues, but owing to the necessity for having additional yard facilities, property was bought for about 100 ft. north and 100 ft. south of 32d Street, between Ninth and Tenth Avenues, and an open excavation, lined with concrete retaining walls and face walls, was made. Between Ninth and Tenth Avenues, 32d Street was closed, and the property formerly the street was bought by the Tunnel Company from the City of New York for a consideration by deed dated April 18th, 1906. The Church, Rectory, and School of St. Michael's, which was located on the west side of Ninth Avenue between 31st and 32d Streets, was acquired by the Tunnel Company after it had acquired property for and had built a similar institution on the south side of 34th Street west of Ninth Avenue.

Probably the most interesting feature of this contract was the support and maintenance of Ninth Avenue, which has a three-track elevated railway structure and a two-track surface railway structure, on which it was necessary to maintain traffic while excavation was made to a depth of about 60 ft., and a viaduct was erected to carry Ninth Avenue. The length of this viaduct is about 375 ft., and the steelwork and its erection was done apart from the North River Division work, but all excavation and underpinning was included in this division. The contract for this work on the Terminal Station-West was let to the New York Contracting Company-Pennsylvania

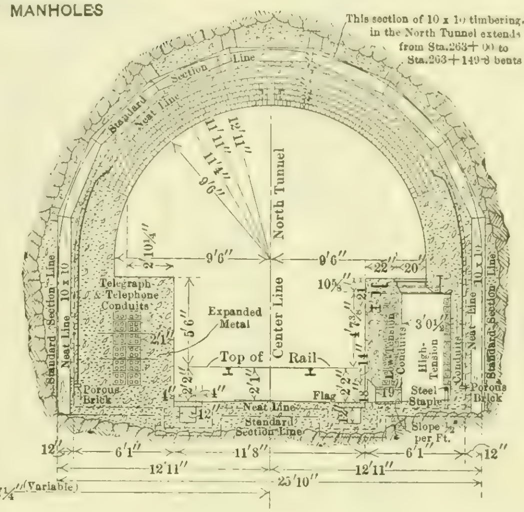
PLATE XXXII.
PAPERS, AM. SOC. C. E.
JANUARY, 1910.
JACOBS ON
NORTH RIVER DIVISION: PENNSYLVANIA RAILROAD.

WEEHAWKEN TUNNELS

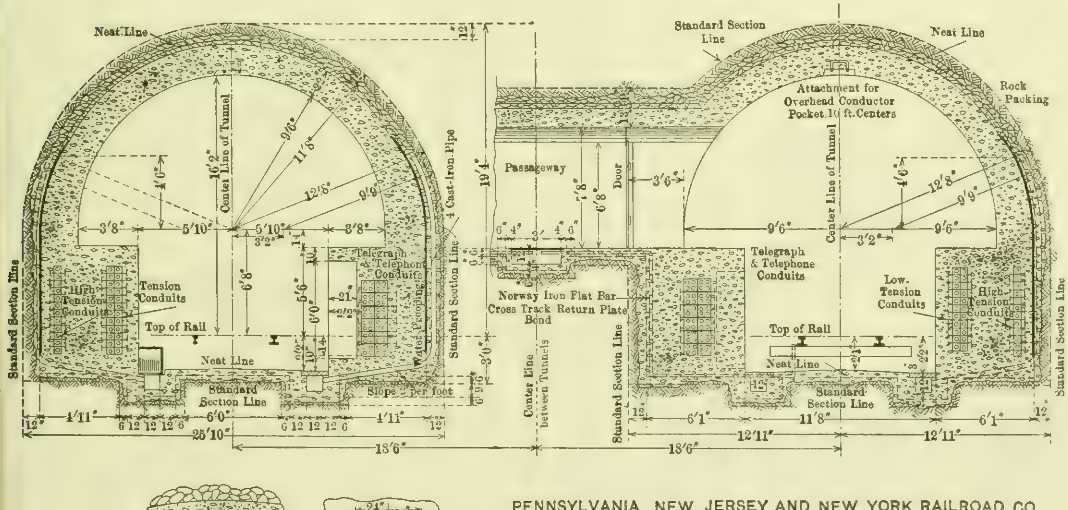
CROSS-SECTION AT MANHOLES

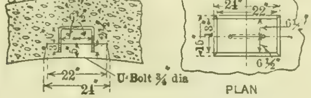


CROSS-SECTION THROUGH T.& T. MANHOLE
Sta. 262+75



CROSS-SECTION THROUGH HIGH TENSION MANHOLE
Sta. 263+00





U-BOLT ATTACHMENT FOR OVERHEAD CONDUCTOR POCKET

PENNSYLVANIA, NEW JERSEY AND NEW YORK RAILROAD CO.
NORTH RIVER DIVISION

BERGEN HILL TUNNELS

TYPICAL SECTION BETWEEN MANHOLES

Terminal, on April 28th, 1906, and included about 517 000 cu. yd. of excavation, about 87% being rock, the construction of about 2 000 lin. ft. of retaining and face walls containing about 18 500 cu. yd. of concrete, and a large quantity of structural steel (1 475 000 lb.) for temporary use in underpinning Ninth Avenue.

Fig. 4 shows cross-sections of the Terminal Station-West yard, and Fig. 5 shows the general method of underpinning the Ninth Avenue structures.

River Tunnels.—In the original plan a four-track tunnel was contemplated from the east side of Tenth Avenue to the east side of

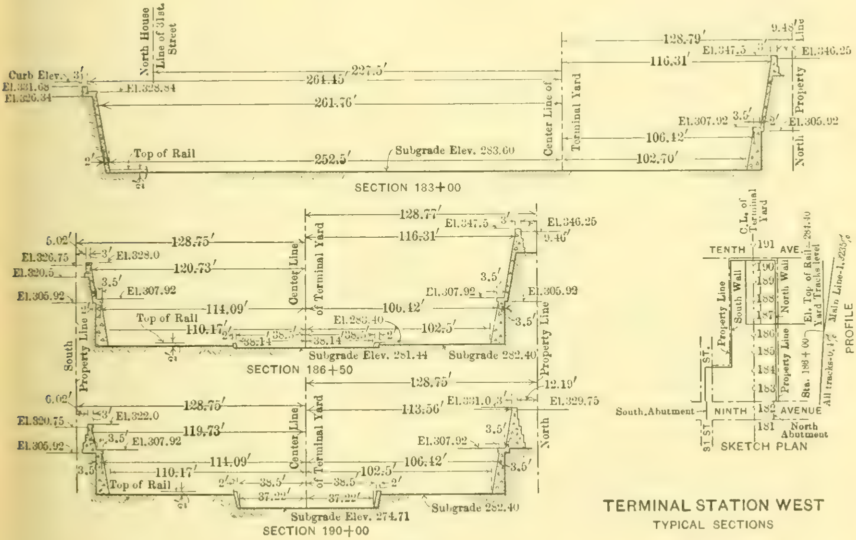


FIG. 4.

Eleventh Avenue, but, owing to the extension of the Terminal Yard, previously noted, this plan was changed, and a two-track structure was built having a central wall between the tracks. This was constructed in tunnel, with the exception of 172 ft. about midway between Tenth and Eleventh Avenues, where the rock dipped below the roof of the tunnel, and there the construction was made in open cut. These tunnels were lined with concrete with brick arches, Figs. 6, 7, and 8 being typical cross-sections. This work was executed by the O'Rourke Engineering Construction Company, under a contract dated November 1st, 1904.

It was possible to excavate in full rock cover about 250 ft. of the tunnels eastward from the Weehawken Shaft and 225 ft. westward from the Manhattan Shaft. At these points the rock cover was very thin, and there shield chambers were made for the erection of two sets of shields, about 6 100 ft. apart. A typical cross-section of the Weehawken Land Tunnel is shown on Plate XXXII.

The Board of Engineers decided, and it was so stated in the contract and specifications, that the river tunnels should be constructed by means of hydraulic shields, but bidders were permitted to present to the Board any scheme on which they might desire to bid, but, of course, the decision as to the practicability of such plans rested with the Board.

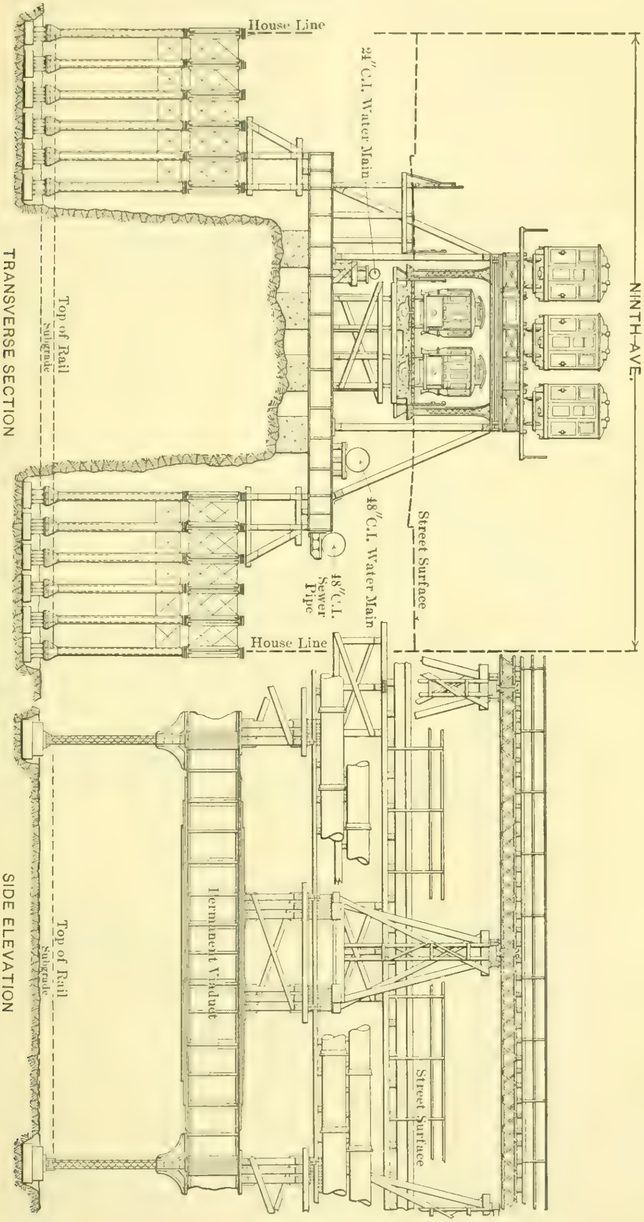
Inasmuch as the shield method of construction was required, the writer designed a shield for use in the North River Tunnels. The shield was about 18 ft. long, over all, and was provided with a rigid but removable hood extending beyond the normal line of the cutting edge, for use in sand, gravel, and ballast, to be removed when the shield reached the silt. The shields were thrust forward by twenty-four rams capable of exerting a pressure of 3 400 tons at a hydraulic pressure of 5 000 lb. per sq. in. Taking into account 30 lb. air pressure, this pressure was increased to 4 400 tons. The shield was fitted with a single hydraulic erector and hydraulic sliding platforms, and when complete weighed 194 tons. Fig. 9 is a back elevation and section of the shield.

The contract for the river tunnels was let to the O'Rourke Engineering Construction Company on May 2d, 1904.

The shields were built in accordance with the design previously referred to, and proved entirely satisfactory. Generally, the materials passed through were as follows: Starting out in full face rock, from it into a mixed face of rock and sand, thence into sand and gravel, full face of sand, piles, rip-rap, and the Hudson silt; and all were fully charged with water.

Compressed air, at an average gauge pressure of about 25 lb. and a maximum of 40 lb. per sq. in., was used in the tunnels from the time the shields emerged from full rock face until the tunnel lining had been joined up and all caulking and grummeting had been done.

Contractor's plants were established at the Weehawken Shaft and at the Manhattan Shaft, including at each, low-pressure air compressors



PENNSYLVANIA TUNNEL & TERMINAL RAILROAD CO.
NORTH RIVER DIVISION
TERMINAL STATION WEST
ARRANGEMENT OF STRUCTURES SUPPORTING
NINTH AVE. DURING PROGRESS OF EXCAVATION
Fig. 5.

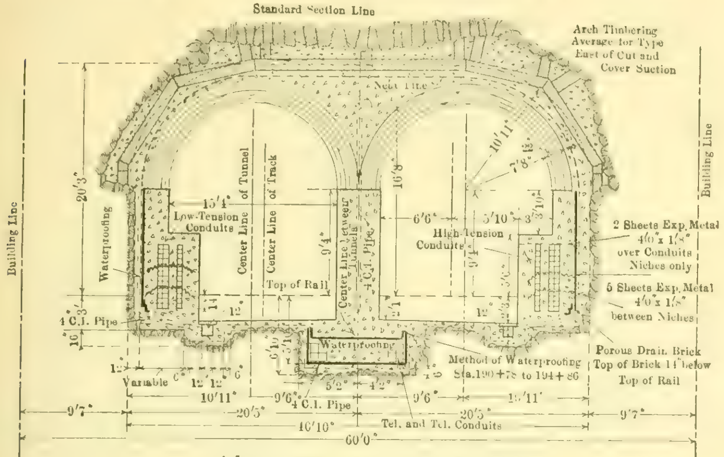
of a capacity of 13 000 cu. ft. of free air per minute and also high-pressure air compressors for drills, hydraulic pumps, electric generators, etc.

The river tunnels passed under Pier 72, North River (old No. 62), which was occupied by the New York Central and Hudson River Railroad Company. The Tunnel Company leased this pier and withdrew all the piles on the lines of the tunnels prior to the commencement of construction, and on the remaining piles constructed a trestle for the disposal of the excavation from the tunnels and the terminal. At the completion of the work this pier had to be restored, and Fig. 10 shows the general arrangements of the location of the piles and the pier structure with reference to the tunnels.

In the tunnels which were constructed in silt farther down the river, by the writer as Chief Engineer for the Hudson Companies, it had been possible to shove the shield through the silt with all the doors closed, displacing the ground and making great speed in construction owing to the absence of all mucking. It was thought that this procedure might be pursued in the larger tunnels of the Pennsylvania Railroad, and it was tried, but it was almost immediately found to be impossible to maintain the required grade without taking a certain quantity of muck into the tunnels through the lower doors, the tendency of the shield being to rise. By taking in about 33% of the excavation displaced by the tunnel, the grade could be maintained. It was considered desirable, owing to this rising of the shields, to increase the weight of the cast-iron lining, and this was done, making the weight of the completed tunnel more nearly equal to the weight of the displaced material. The weight of the cast-iron lining (with bolts) was increased from 9 609 to 12 127 lb. per lin. ft. of tunnel. The weight of the finished tunnel with this heavier iron is 31 469 lb. per lin. ft. The weight of the silt displaced per linear foot of tunnel, at 100 lb. per cu. ft., is 41 548 lb. The weight of the completed tunnel with the maximum train load is 41 869 lb. per lin. ft.

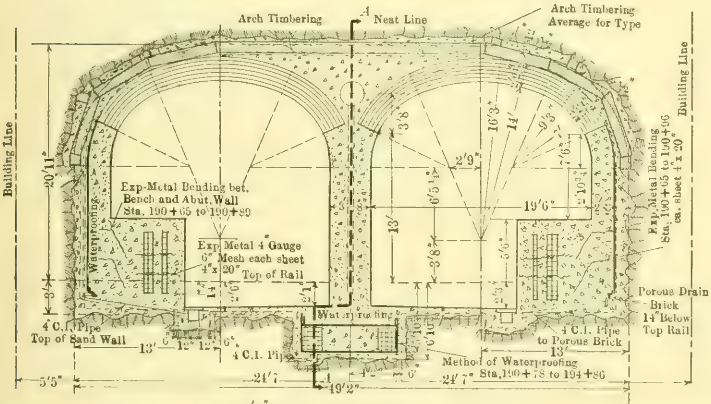
The maximum progress at one face in any one month was 545 ft., working three 8-hour shifts, and the average progress in each heading while working three shifts was 18 ft. per 24 hours; while working one shift with the heavier lining referred to above, the delivery of which was slow, the average progress was 11 ft. per 24 hours.

In order to permit the screw-piles to be put in place through the



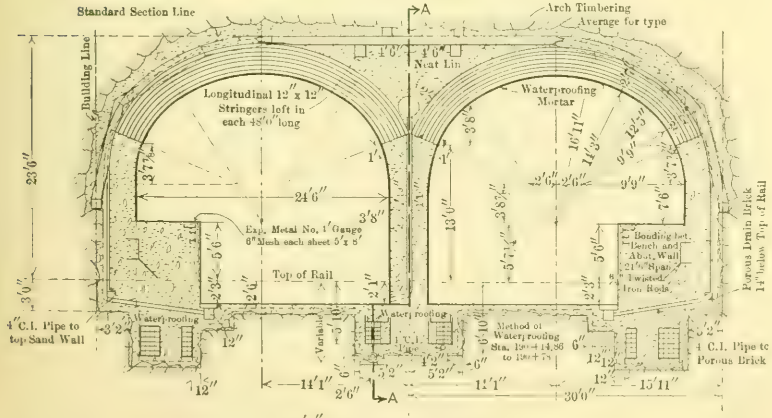
15'-4" Span Twin Tunnels. Rock Roof.

FIG. 6.



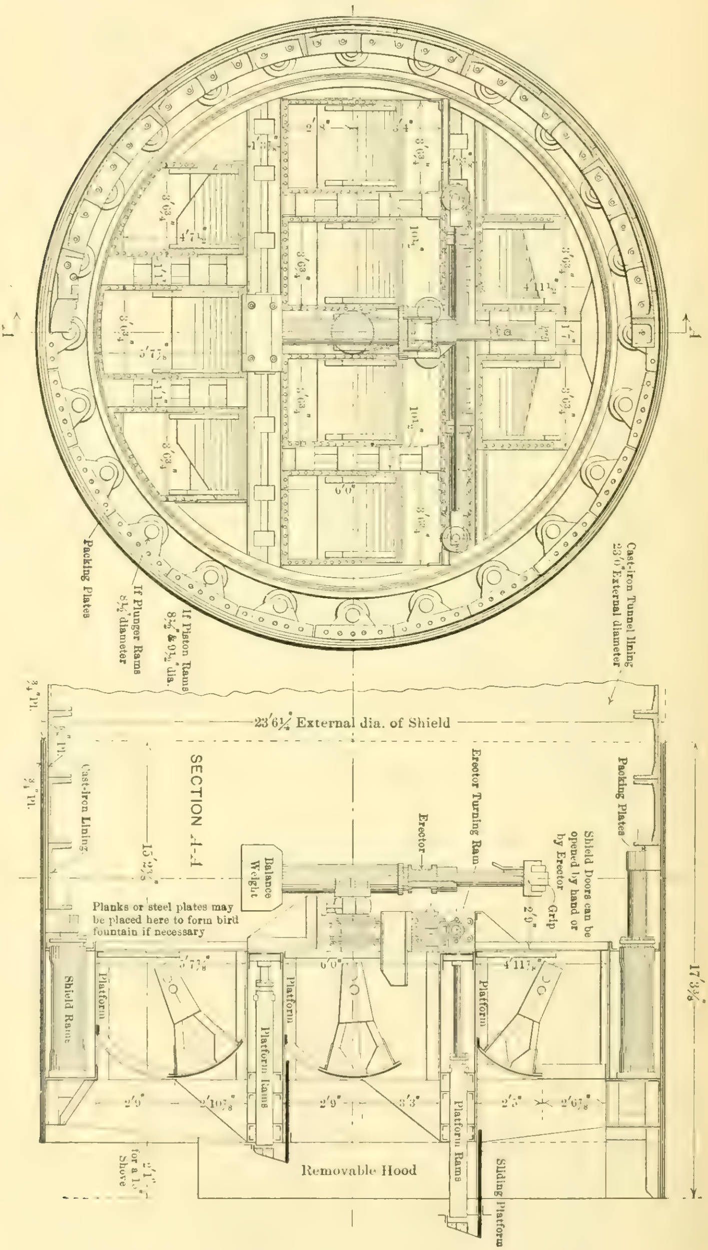
19'-6" Span Twin Tunnels.

FIG. 7.



23'6" SPAN TWIN TUNNELS

FIG. 8.



BACK VIEW OF SHIELD

PROPOSED SHIELD FOR SUBAQUEOUS TUNNELING
GENERAL ELEVATION
FIG. 9.

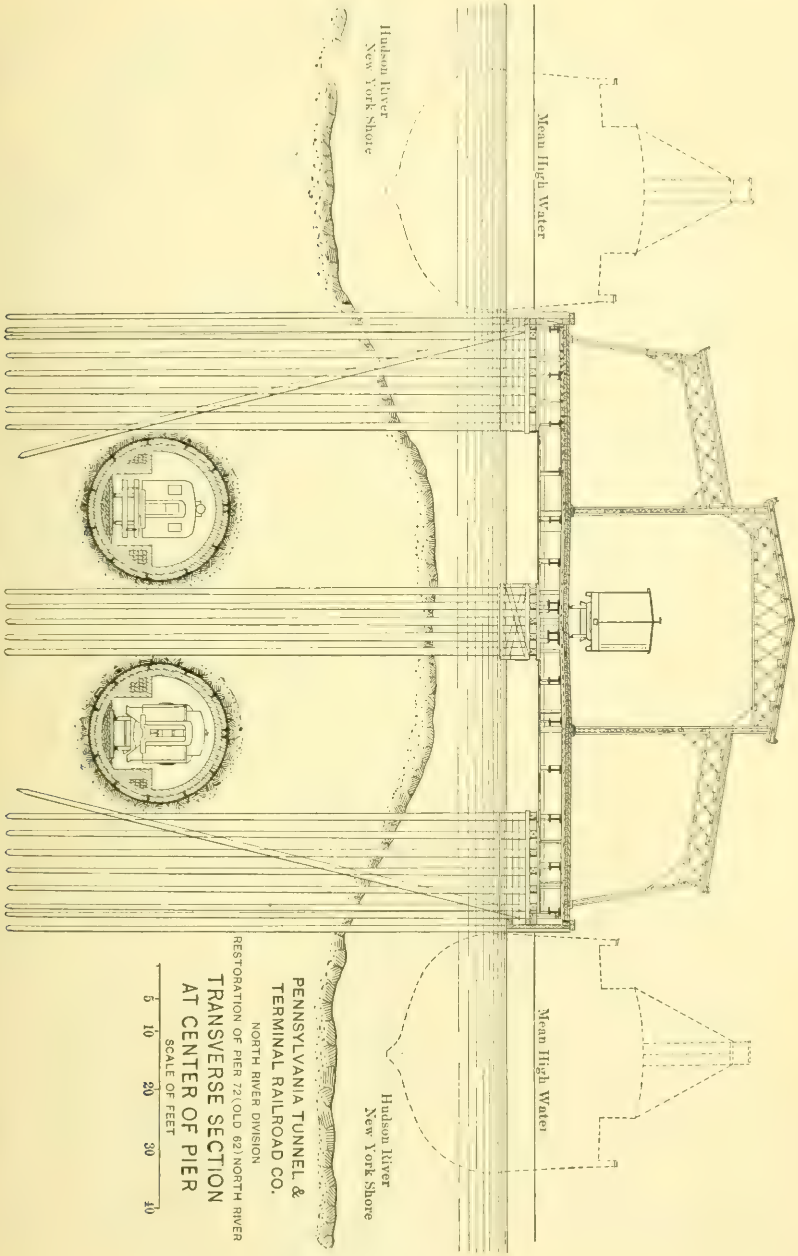

Mean High Water
Hudson River
New York Shore
Mean High Water
Hudson River
New York Shore
PENNSYLVANIA TUNNEL &
TERMINAL RAILROAD CO.
NORTH RIVER DIVISION
RESTORATION OF PIER 72 (OLD 62) NORTH RIVER
TRANSVERSE SECTION
AT CENTER OF PIER
SCALE OF FEET
5 10 20 30 40

Fig. 10.

lining, cast-steel bore segments were designed, and placed in the invert at 15-ft. centers; these are of such a design as to permit the blade and shaft of the screw-pile to be inserted without removing any portion of the lining. Fig. 11 is a typical cross-section of the river tunnel, as originally planned, with these pile supports.

After the shields had met and the iron lining was joined up, various experiments and tests were made in the tunnel; screw-piles, and 16-in. pipes, previously referred to, were inserted through the bore segments in the bottom of the tunnel, thorough tests with these were made, levels were observed in the tunnels during the construction and placing of the concrete lining, an examination was conducted of the tunnels of the Hudson and Manhattan Railroad Company under traffic, and the result of these examinations was the decision not to install the screw-piles. The tunnels, however, were reinforced longitudinally by twisted steel rods in the invert and roof, and by transverse rods where there was a superincumbent load on the tunnels; it might also be noted that on the New York side, where the tunnels emerge from the rock and pass into the soft material, the metal shell is of cast steel instead of cast iron. Fig. 12 is a typical cross-section of the river tunnels as actually constructed.

During the investigations in the tunnels, borings were made to determine exactly the character of the underlying material, and it was then found that the hard material noted in the preliminary wash-borings was a layer of gravel and boulders overlying the rock. When the borings in the tunnels reached this material it was found to be water-bearing and the head was about equivalent to that of the river. Rock cores were taken from these borings, and the deepest rock was found at about the center of the river at an elevation of 302.6 ft. below mean high water. Rods were then inserted in each bore hole and thereby attached to the rock and used as bench-marks in the tunnels. From these bench-marks, using specially designed instruments, very accurate observations of the behavior of the tunnels could be made, and from these the very interesting phenomenon of the rise and fall of the tunnels with the tide was verified, the tunnels being low at high tide and the average variations being about 0.01 ft. in the average tide of about 4.445 ft.: the tidal oscillations are entirely independent of the weight of the tunnels, since observations show them to have been the same both before and after the concrete lining was in position. There was

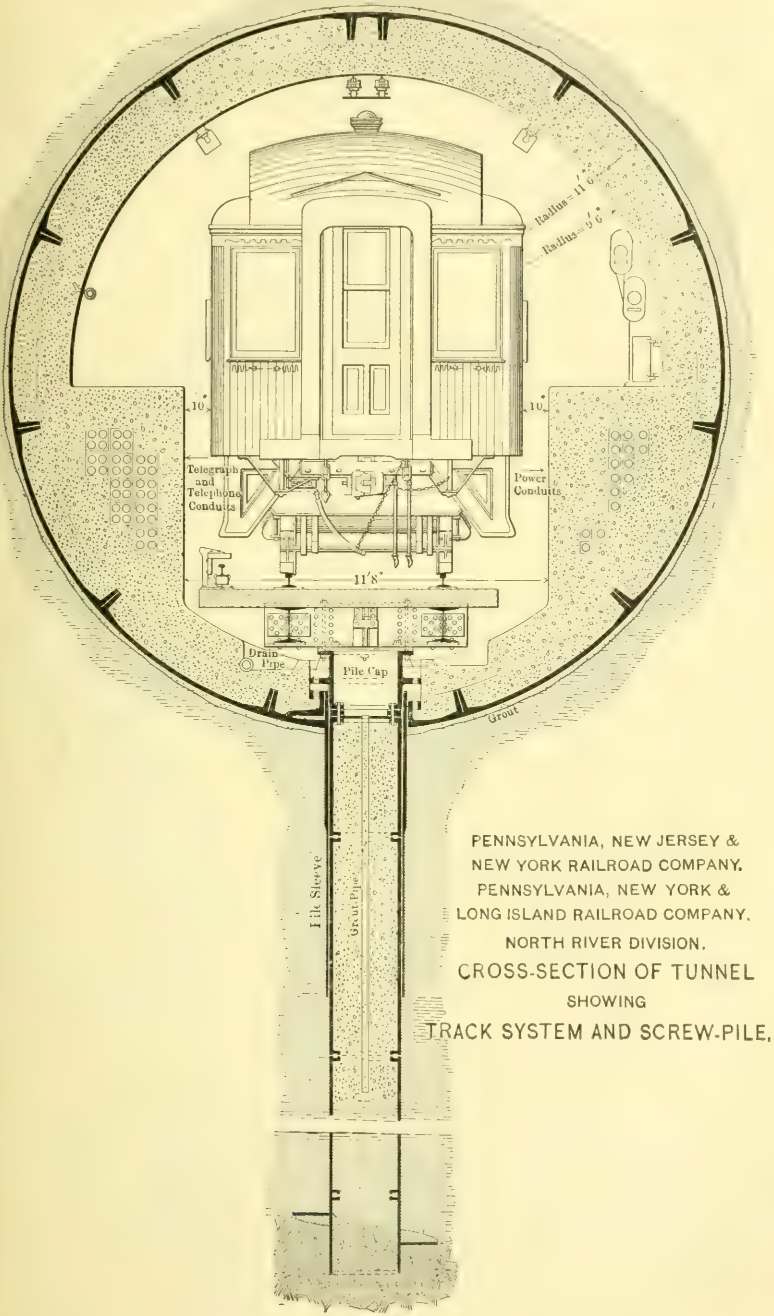

Radius=11'6"
Radius=9'6"
10"
10"
Telegraph and Telephone Conduits
Power Conduits
11'8"
Drain Pipe
Pile Cap
Grout
Pile Sleeve
Grout Pipe
PENNSYLVANIA, NEW JERSEY &
NEW YORK RAILROAD COMPANY.
PENNSYLVANIA, NEW YORK &
LONG ISLAND RAILROAD COMPANY.
NORTH RIVER DIVISION.
CROSS-SECTION OF TUNNEL
SHOWING
TRACK SYSTEM AND SCREW-PILE.

Fig. 11.

considerable subsidence in the tunnels during construction and lining, amounting to an average of 0.34 ft. between the bulkhead lines. This settlement has been constantly decreasing since construction, and appears to have been due almost entirely to the disturbances of the surrounding materials during construction. The silt weighs about

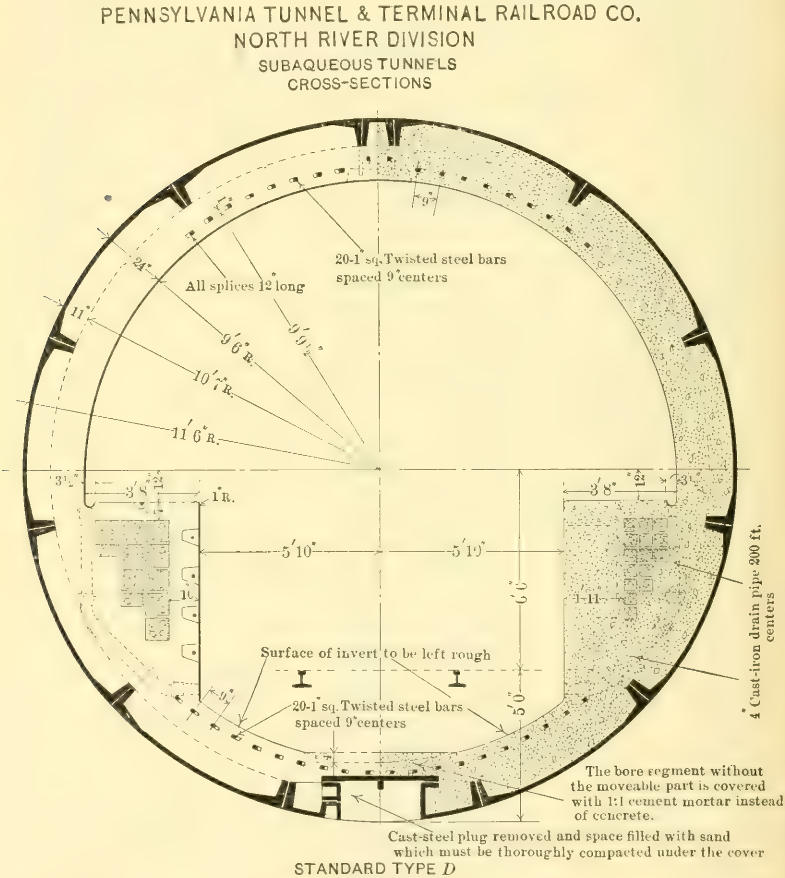


FIG. 12.

100 lb. per cu. ft. (this is the average of a number of samples taken through the shield door, and varied from 93 to 109 lb. per cu. ft.), and contains about 38% of water. It was found that whenever this material was disturbed outside the tunnels a displacement of the tunnels followed. The tunnels as above noted have been lined with con-

crete reinforced with steel rods, and prior to the placing of the concrete the joints were caulked, the bolts grummeted, and the tunnels rendered practically water-tight; the present quantity of water to be disposed of does not exceed 300 gal. per 24 hours in each tunnel 6 100 ft. long.

Bergen Hill Tunnels.—These are two single-track tunnels, 37 ft. from center to center, and extend for a distance of 5 940 ft. from the Weehawken Shaft to the Hackensack Portal. They were built almost entirely through trap rock. The contract was let on March 6th, 1905, to the John Shields Construction Company, but was re-let on January 1st, 1906, to William Bradley, the Shields Company having gone into the hands of a receiver. About 1 369 ft. of the tunnel excavation was done by the Shields Company, but no concrete lining. The maximum monthly progress for all headings was 622 ft., and the average progress was 338 ft. A working shaft 216 ft. deep was sunk from the top of the hill, to facilitate construction. The tunnels are lined with concrete throughout. Typical cross-sections of these tunnels are shown on Plate XXXII.

In conclusion it may be admissible for the writer after having, in conjunction with Mr. Samuel Rea, experienced the evolution and materialization of this Pennsylvania Railroad scheme, to express his great sorrow for the untimely death of the father of the entire scheme, the late President Cassatt.

Vol. XXXVI. JANUARY, 1910. No. 1.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

NOTES ON THE REPLACING OF THE SUPERSTRUCTURE OF THE HARLEM SHIP CANAL BRIDGE.

Discussion.*

By Messrs. Lincoln Bush and Martin Gay.

Mr. Bush. Lincoln Bush, M. Am. Soc. C. E. (by letter).—In reference to the use of sand jacks for lowering the draw-bridge of the Delaware, Lackawanna and Western Railroad over the Passaic River at Newark, N. J., on December 20th, 1903, the following comments are offered:

On the day the bridge was moved and lowered, rain commenced at 1.20 A. M., and continued until 5.00 P. M., at which time the bridge rested on the new center pier in exact position, the precipitation during this time being 1.23 in. In order to keep the sand dry while the sand boxes were being filled and for the same purpose after they were filled, tarpaulins had been provided prior to the operation. During the night prior to the move, one of the tarpaulins accidentally became partly removed on the south side of one of the four boxes, letting some water into the sand near the top of the box. This wet sand, however, caused a delay of only 20 min. in the lowering, and, aside from this incident, there was not the least difficulty in keeping the sand dry, even with the heavy precipitation of 1.23 in.

Mr. Howe mentions the irregular setting and lost time in balancing the movement. He probably refers to the lowering of one end of the bridge at a time, which was done in 2-ft. stages. The day was chilly,

*This discussion (of the paper by Horace J. Howe, M. Am. Soc. C. E., printed in *Proceedings* for November, 1909, and presented at the meeting of January 5th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

and the men were wet to the skin. The writer was reasonably certain that the operation could be completed on schedule time, by handling the lowering slowly and carefully, rather than by seeing how quickly it could be done, and, instead of lowering both ends of the bridge at the same time, he adopted the plan already mentioned. It was shown by tests made with test sand boxes, and in the actual lowering of the bridge itself, that the bridge could be lowered very readily at the rate of 3 in. per min. Mr. Bush.

Observations on the tide movements at the bridge site for four months, and other reliable data, showed that at times the minimum low tide did not fall below zero or mean tide, and that the maximum low tide frequently fell to an elevation of 3 ft. below mean tide. These data also showed that at times the high tide did not go above mean tide, and that the maximum high tide at times rose to a point 4 ft. above mean tide. These observations showed that the minimum variation between high and low tide was nothing, and that the maximum variation was 7 ft. The normal variation for low tide at the bridge site is —2.5 ft. (below mean tide), and the normal variation for high tide is +2.5 ft. (above mean tide).

The work had to be done, as planned, in 12 hours, in other words, from low tide to low tide. When the four barges were run under the bridge, the low tide was —1.9 ft., and when they were released at the next low tide, fell to only —1 ft. instead of a normal low tide of —2.5 ft. The high tide rose to +3.0 ft. instead of a normal high tide of +2.5 ft.

The tests made with test sand boxes showed with most convincing evidence that dry sand, carrying a load of about 2 500 lb. per sq. ft., produced very little lateral pressure; and no outward deflection of the timber, with a straight-edge on the sides of the boxes, was discernible. Neither was there any perceptible deflection in the sides of the timber boxes used in lowering the bridge, except with one box where wet sand occurred, and, as stated, this was relieved with a delay of only 20 min. by opening the sand holes lower down in the box where dry sand flowed out freely.*

The fact that the work was done on schedule time, as planned, with abnormal tide conditions and a heavy rainfall continuing throughout the operation, should be convincing evidence that this method of lowering a heavy structure, tempered with good judgment, is perfectly safe, economical, and efficient.

Martin Gay, M. Am. Soc. C. E.—When the proposal was first made to run the trains of the Rapid Transit Railroad across the Harlem Ship Canal Bridge, it was thought feasible to add an upper deck to the old draw-span and to build new spans above the old approaches. Mr. Gay.

* An accurate and full presentation of this operation and the tests made prior to it are given in *Engineering News*, December 31st, 1903.

Mr. Gay. This was objected to by the Department of Bridges, under the jurisdiction of which the bridge came, on the ground that the turn-table, though well designed and sufficient to carry its comparatively light load of some 700 tons, was not substantial enough to endure the racking and distortions due to a moving load of perhaps twice that weight.

While this point was under discussion by the engineers of the Department of Bridges and the Rapid Transit Commission, several other interests came into view. For some years the Kingsbridge Railroad Company had held a franchise permitting it to cross the bridge, and its officers had discussed the question with sufficient seriousness to cause the Department of Bridges to make a study of the situation and to determine that it would be necessary to strengthen the floor system and practically rebuild it at a higher elevation, and also to change the grade of the approaching streets. This would have been a matter of considerable expense.

Also, the New York Central Railroad, in connection with the plan for the elimination of grade crossings, had prepared to abandon the long curve with many crossings through Kingsbridge Village, and to cross from the east bank of the Harlem River to the east bank of the Hudson, following the north bank of the Ship Canal and passing under the Ship Canal Bridge. To do this an additional space of 12 ft. was required between the bulkhead of the canal and the north abutment of the bridge.

Also, at this time the Department of Bridges was planning a new bridge across the Harlem, near Fordham Landing, and had about determined to build a double-leaf rolling lift of the Scherzer type.

It was to the combination of these various interests that we owe this admirable paper. Each party to the combination contributed its share of the cost of the project, either in money or in work, or both, and each got what it wanted.

Mr. Howe has described the work of moving the bridge so clearly that little can be said on that head.

Each of the six operations, that is, moving out an old span or moving in a new one, was not of itself a very complex problem, but, taken altogether, it was a work of considerable magnitude, and considering the cramped space in which the contractor was obliged to maneuver the approach spans, the uncertainty of the tides, and the short space of time during which he could obstruct travel, the problem was one requiring nice calculation and unusual judgment.

The time during which street travel could be obstructed was fixed by the Department of Bridges, whose duty it was to consider the convenience of the public, after consultation with Messrs. Terry and Tench, as to the methods they proposed to use and the time they would require. The Department was not willing to deprive people of an

opportunity to cross the stream for a longer time than necessary and did not wish to impose oppressive conditions on the contractors. Mr. Gay.

It was estimated that one day would be sufficient to move and re-adjust each of the approach spans, allowing for accidents and delays, and that 3 days would be required for the draw-span. Therefore, the permit allowed street travel to be interrupted for a total time of 5 days, but not for more than 3 days consecutively. That no very serious delays occurred is indicated by an analysis of Mr. Howe's figures, which shows that the total time of interrupted travel was 3 days, 16 hours, 35 min., and that during the moving of the draw-span, the interruption was 4 hours, 55 min. less than the stipulated 3 days.

Each of the three new spans was put to use by vehicles and pedestrians as soon as it was placed in position, and the draw-span was opened to pass vessels without causing any delay to river traffic.

The old spans which have become a part of the University Heights Bridge had to have considerable changes in order to bring them up to modern requirements, and they have done duty continuously since the formal opening of the bridge.

In all operations of this nature on the Harlem River, of which there is any record, the rise and fall of the tide has been counted on as a factor and has been used to some purpose, and yet it is such an uncertain factor that in almost every case, other means for raising or lowering have been provided and usually resorted to, in order to supplement the deficiency of tidal power. As the movements of the tides, of greater or less extent, take place at more or less definitely known times, they must be reckoned with. On a non-tidal stream, however, where other power would of necessity be provided, the attendant uncertainty and anxiety regarding the behavior of the tide would be eliminated, and probably the cost would not be greatly increased.

One occasion on which the lifting power of the tide was used to good advantage, but perhaps not with any great economy, was in the moving of the draw-span of the old Macomb's Dam Bridge, of which Mr. Howe has spoken. The bridge was built in the early Sixties, and was replaced in 1892 by the present structure, which was designed and the construction supervised by A. P. Boller, M. Am. Soc. C. E. It was necessary to remove the old bridge to make way for the new one, and it was also necessary to provide for public travel. It was decided, therefore, to move the draw one block north of the old site, to the line of 156th Street. A pivot pier and approaches having been constructed at an elevation 12 ft. lower than that of the bridge, the problem was to move the draw-span about 200 ft. north, and to lower it 12 ft. to its new position without obstructing navigation. This was done by lifting the span on two scows and a cribbing of 12 by 12-in. timbers, and towing it to a pile and cribbing pier which had been built near the bank of the stream and out of the course of passing vessels.

Mr. Gay. Here it was deposited safely at an elevation somewhat lower than that from which it had started. When the next flood tide raised the scows and bridge, a course of crib timbers was pulled off the pier, and as the span settled with the ebb tide and rested, a course of crib timbers was taken off the scows. As the next flood tide freed the span from the pier, another course of timbers was removed and so on, until it rested at the proper elevation to be floated across to the permanent pier and be placed in position.

An instance of the tide not doing its duty, as expected, was at the moving of the Madison Avenue draw-span, where an east storm made an early flood which caught and held the scows under the span after it had been landed. Considerable damage might have resulted, but for the scuttling of one of the scows.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will be reproduced in the volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

ELSTNER FISHER, M. Am. Soc. C. E.*

DIED OCTOBER 12TH, 1909.

Elstner Fisher, the son of Mr. and Mrs. William Mack Fisher, was born in Cincinnati, Ohio, on October 9th, 1853. He received his education at private schools in Cincinnati, and at the Central High School of Philadelphia (afterward the University of Pennsylvania), from which he was graduated with the degree of Bachelor of Arts.

In 1872, Mr. Fisher was appointed to the United States Naval Academy, from which he was graduated in 1876. He was assigned to the U. S. S. *Vandalia*, as Midshipman, and for two years served on the staff of General Grant, who made that vessel his headquarters during the Mediterranean part of his trip around the world. Mr. Fisher also made a four years' cruise on the *Wachusetts*, around the Horn and up the Pacific Coast as far as San Francisco.

In 1882, he was detailed as Assistant to the U. S. Coast and Geodetic Survey, and, in that capacity, made deep-sea soundings from Boston, Mass., to Rio de Janeiro, Brazil. Owing to the illness of the Commanding Officer, Mr. Fisher had charge of the work of the expedition. He was afterward engaged in making surveys of Delaware River and Bay, Cape Romaine, South Carolina, and Long Island Sound.

In January, 1884, Mr. Fisher resigned his commission in the Navy and entered the employ of the Pennsylvania Railroad, serving as Chainman, Rodman, and Transitman on the location of the Schuylkill Valley Railroad. On the completion of this work, he was transferred to Altoona, Pa., as Assistant Engineer in the Maintenance-of-Way Department, being engaged on the location and construction of various branch lines and in general engineering work. In July, 1886, Mr. Fisher was appointed Assistant Supervisor on the Monongahela Division of the Pennsylvania Railroad, from Pittsburg to Monongahela City.

In 1887 he accepted the position of Assistant Engineer on the Michigan Central Railroad, with headquarters at Detroit, Mich. He was afterward transferred to the Operating Department and served in various capacities, namely, Night-Yardmaster, Yardmaster, Assistant Trainmaster, Trainmaster, and Assistant Superintendent of the Middle Division, with headquarters at Jackson, Mich.

* Memoir prepared by R. L. Latham, Esq., Chief Engineer of the Toronto, Hamilton & Buffalo Ry. Co.

In November, 1897, Mr. Fisher was appointed General Superintendent and Chief Engineer of the Toronto, Hamilton and Buffalo Railway, which position he resigned shortly before his death on October 12th, 1909.

In 1883, he married Miss Sarah Burt, the daughter of Mr. and Mrs. Wells Burt, of Detroit, Mich.

Mr. Fisher was elected a Junior of the American Society of Civil Engineers on April 3d, 1889, an Associate Member on June 2d, 1897, and a Member on March 5th, 1902.

He was also a Member of the Canadian Society of Civil Engineers; the Transportation Club of New York; the Buffalo Club of Buffalo; the Hamilton Club of Hamilton; the Brantford Club of Brantford; the Royal Hamilton Yacht Club; the Caledon Mountain Trout Club; and the Barton Lodge, A. F. and A. M., Hiram Chapter, R. A. M.

ALBERT STANLEY RIFFLE, M. Am. Soc. C. E.*

Died October 28th, 1909.

Albert Stanley Riffle was of German-Swiss parentage. He was born on March 26th, 1860, at Somerset, Pa., and died at Sierra Madre, Cal., on October 28th, 1909. He was the son of William and Mary E. (Speicher) Riffle.

At the age of 11 years, he removed with his parents to a farm near Springhill, Kans. Here his early life was spent until his entrance as a student into the Kansas State University, from which institution he was graduated with the degree of B. S., in 1884. From this time until 1902 he was actively engaged in the practice of the profession of civil engineering. At the latter date commenced his long and valiant contest with the insidious ailment which finally caused his death.

Mr. Riffle's principal professional engagements were as follows:

From 1884 until 1889 he was in the employ of the Northern Pacific Railroad on the construction of the Cascade Division, most of the time under Virgil G. Bogue, M. Am. Soc. C. E., who was then acting as Principal Assistant Engineer on that road. Mr. Riffle served in various grades, both in active charge of construction work and on location, most of his services, however, being rendered as Superintendent of Bridges and Buildings. In this capacity he prepared the designs of practically all the truss and trestle bridgework, and carried to completion the construction of the bridge across the Columbia River at Pasco. He was placed in charge of this latter work after the substructures and some falsework were in position, succeeding the late L. L. Buck, M. Am. Soc. C. E., who initiated the work.

In 1889-90, Mr. Riffle acted as Principal Assistant Engineer to his brother, Franklin Riffle, M. Am. Soc. C. E., then Chief Engineer of the Oregon and Washington Territory Railroad, and, in this capacity, had charge of the planning and erection of most of the bridgework on that road.

The years 1890-92 were spent in Peru, whither he was sent at the suggestion of Mr. L. L. Buck, by William R. Grace and Sons, to take charge of the erection of the great Verrugas Viaduct, built to replace one erected at an earlier date by Mr. Buck, which had been destroyed by a great flood. This work, which was quite fully described in the engineering journals at the time, was successfully carried through under difficult and very unusual conditions arising from the mixed and uncertain character of the available labor, and, chiefly, because of the great fatality from Verrugas fever among all engaged on the work.

* Memoir prepared by Arthur L. Adams, M. Am. Soc. C. E.

The writer recalls that of four skilled erecting foremen taken by Mr. Riffle from New York for this work, only one returned; and that of three clerks in his office on the work, he buried two. Mr. Riffle himself suffered two attacks of the fever and also contracted the Panama fever on his return, and continued to suffer from the effects of this experience for years afterward.

From 1892 to 1895 he was associated with his brother and others under the name of the Oregon Bridge Company, with offices at Portland, Ore. This company was engaged in general contract work, chiefly in the construction of highway bridges throughout the States of Oregon and Washington.

In the years 1897 to 1899, Mr. Riffle was in the employ of the Valley Road, now constituting the Santa Fé's System in California, north of Bakersfield, being, for a part of this time, in charge of the design of all structures, under W. B. Storey, Jr., M. Am. Soc. C. E., and later in charge of the Franklin Tunnel and other important structures, under W. C. Edes, M. Am. Soc. C. E., the Assistant Chief Engineer.

From 1899 to the time when ill health compelled his discontinuance of active work, Mr. Riffle was in the employ of the Excelsior Wooden Pipe Company, of San Francisco, and was engaged in the construction, as Contractor, of wooden stave pipe and other water-works structures. During this period he had charge, under D. C. Henny, M. Am. Soc. C. E., the General Manager, of carrying out numerous contracts on important pipe-line and reservoir construction. During his active career Mr. Riffle filled many other important engagements, such as experting the designs for a number of the World's Fair Buildings for the Columbian Exposition at Chicago, under the direction of Mr. Bogue, and the making of expert valuations on water-works properties at Oakland, Cal., and at Albuquerque, N. Mex.

As an engineer Mr. Riffle possessed attainments of a very high order, much higher indeed than the scope of his practice ever gave him opportunity to exemplify. These attainments, because of some natural diffidence, were best appreciated by the men of his own profession, those standing high in public and professional esteem often availing themselves of his special knowledge. He combined, in an unusual degree, thoroughness and knowledge of detail, with an exceptional capacity for rapid and successful execution of work.

His contribution to professional progress is represented chiefly by a paper, prepared by Mr. Franklin Riffle and himself, descriptive of the successful laying of a large submerged pipe across the Willamette River at Portland, Ore.* His greatest contribution, however, is undoubtedly to be found in the power of his example of faithful service and successful accomplishment in the discharge of the responsibilities

* *Transactions*, Am. Soc. C. E., Volume XXXIII, p. 257, 1895.

which came to him in the practice of his profession during the years of his active life.

Personally, Mr. Riffle was a man of sterling character, and possessed of qualities of heart and mind which greatly endeared him to his friends, and indeed to all who were favored with his intimate acquaintance. His splendid pluck and sustained buoyancy of spirit during the long years of unavailing struggle against disease, prior to his death, gave touching evidence of the inherent strength of the man, and of his faith in the overruling Power. He is survived by his wife, Mrs. Bella Love Riffle.

Mr. Riffle was elected a Member of the American Society of Civil Engineers, on May 7th, 1890.

ERNEST STEARNS BALL, Jun. Am. Soc. C. E.*

DIED NOVEMBER 22D, 1909.

Ernest Stearns Ball, the son of Henry Eugene and Julia (Blandin) Ball, was born in Gardner, Mass., on August 17th, 1882. He prepared for college at the Gardner High School, and in 1899, entered Norwich University from which he was graduated in 1903 with the degree of B. S. in Civil Engineering.

From June, 1903, to June, 1904, Mr. Ball was employed as Draftsman by the Riter Conley Manufacturing Company, of Pittsburg, Pa., and from June, 1904, to July, 1905, he was with the firm of Post and McCord, of New York City, on steel construction work.

From that time until December, 1906, Mr. Ball was in business as a Contracting Engineer, designing and constructing power-houses, tanks, foundations, etc. He was afterward engaged in miscellaneous work in Northfield and Roxbury, Vt., until May, 1909, when he was appointed Assistant Engineer in the Maintenance-of-Way Department of the Missouri Pacific Railroad, which position he held until his death, in the Missouri Pacific Railroad Hospital, at St. Louis, Mo., on November 22d, 1909.

Mr. Ball is survived by his wife, Myrta M. (Tarbell) Ball, and one son, Theodore Macklin Ball.

Mr. Ball was elected a Junior of the American Society of Civil Engineers on May 2d, 1905.

* Memoir prepared by Arthur E. Winslow, Assoc. M. Am. Soc. C. E.

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PROCEEDINGS

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OF

CIVIL ENGINEERS

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ON BITUMINOUS MATERIALS FOR ROAD CONSTRUCTION: W. W. Crosby, A. W. Dean, H. K. Bishop, A. H. Blanchard.

The House of the Society is open from 9 A.M. to 10 P.M. every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

HOUSE OF THE SOCIETY—220 WEST FIFTY-SEVENTH STREET, NEW YORK.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PROCEEDINGS

This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS

CONTENTS

MINUTES OF MEETINGS

OF THE SOCIETY

FIFTY-SEVENTH ANNUAL MEETING.*

January 19th, 1910.—The meeting was called to order at 10 A. M.; President Onward Bates in the chair; Chas. Warren Hunt, Secretary; and present, also, about 245 members.

Messrs. Horace J. Howe, W. J. Carter, and L. S. Cowles were appointed tellers to canvass the Ballot for Officers for the ensuing year.

The Annual Report of the Board of Direction, and the Annual Reports of the Secretary and of the Treasurer,† for the year ending December 31st, 1909, were presented and accepted.

* A full report of the Fifty-seventh Annual Meeting is printed on pages 57 to 78 of this number of *Proceedings*.

† For these reports see pages 11 to 20 of *Proceedings* for January, 1910 (Vol. XXXVI).

The following were appointed members of the Nominating Committee to serve two years:

JAMES C. MEEM..........	*Representing*	*District*	*No.*	*1*
J. R. WORCESTER..........	"	"	"	*2*
HENRY C. ALLEN..........	"	"	"	*3*
J. E. GREINER............	"	"	"	*4*
ISHAM RANDOLPH..........	"	"	"	*5*
RICHARD MONTFORT........	"	"	"	*6*
R. H. THOMPSON..........	"	"	"	*7*

The Secretary presented a report from the Special Committee on Steel Columns and Struts.*

The report was accepted and ordered printed, and the Committee was continued.

The Secretary presented a report from the Special Committee on Bituminous Materials for Road Construction.†

The report was accepted and ordered printed, and the Committee was continued.

The Secretary presented a report from the Special Committee on Rail Sections.‡

The report was accepted.

Desmond FitzGerald, Past-President, Am. Soc. C. E., Chairman of the Special Committee on Engineering Education, presented a Progress Report of that Committee.§

The report was accepted as a progress report, and the Committee continued.

The Secretary presented a report from the Special Committee on Uniform Tests of Cement, and also a Minority Report from Alfred Noble, Past-President, Am. Soc. C. E.||

After discussion, it was ordered that the report be accepted, and the Committee continued and directed to make a final report at the next Annual Meeting.

D. A. Molitor, M. Am. Soc. C. E., presented a report from the Special Committee on the Status of the Metric System.¶

After discussion, the report was accepted and the Committee was discharged.

The Secretary presented a letter from the Members of the American Society of Civil Engineers residing in St. Louis and vicinity, stating that their Second Annual Dinner would be given on Thursday evening, January 20th, 1910. On motion, duly seconded, the Secretary was instructed to send congratulations to the St. Louis Members, and thank them for their letter.

* This report was printed in *Proceedings*, Vol. XXXV, page 519 (December, 1909).

† This report was printed in *Proceedings*, Vol. XXXV, page 517 (December, 1909).

‡ See page 62.

§ See page 65.

|| See pages 66 and 67.

¶ See page 69.

The Secretary made some announcements in reference to the programme of the Annual Meeting.

The Secretary presented the report of the Special Committee on Concrete and Reinforced Concrete.*

The report was accepted and the Committee continued.

The report of the tellers appointed to canvas the Ballots for Officers for the ensuing year was presented.

The President announced the election of the following Officers:

President, to serve one year:

John A. Bensel, New York City.

Vice-Presidents, to serve two years:

John T. Fanning, Minneapolis, Minn.
Hunter McDonald, Nashville, Tenn.

Treasurer, to serve one year:

Joseph M. Knap, New York City.

Directors, to serve three years:

William E. Belknap, New York City.
Horace Loomis, New York City.
George A. Kimball, Boston, Mass.
Percival Roberts, Jr., Philadelphia, Pa.
Charles F. Loweth, Chicago, Ill.
Arthur DeWint Foote, Grass Valley, Cal.

Mr. Macdonald and Mr. Stearns conducted Mr. Bensel, the President-elect, to the chair.

Mr. Bensel addressed the meeting briefly.

Adjourned.

February 2d, 1910.—The meeting was called to order at 8.30 P. M.; Gardner S. Williams, Director, Am. Soc. C. E., in the chair; T. J. McMinn, Assistant Secretary, acting as Secretary; and present, also, 125 members and 18 guests.

A paper by T. Kennard Thomson, M. Am. Soc. C. E., entitled "Underpinning the Cambridge Building, New York City," was presented by the author and illustrated with lantern slides. The Assistant Secretary read a communication on the subject from D. L. Hough, M. Am. Soc. C. E., and the subject was discussed orally by Messrs. H. G. Opdycke, E. A. Yates, Ogden Merrill, O. Lowinson, J. C. Meem, and the author.

A paper by William B. Bamford, Assoc. M. Am. Soc. C. E., entitled "Building Agreements," was presented by the author and dis-

* See page 76.

cussed by Messrs. W. G. Wilkins, W. A. Boring, T. Kennard Thomson, J. C. Wait, W. L. Bowman, C. A. Ruggles, and O. Lowinson.

Owing to the lateness of the hour, written discussions by Messrs. Norman R. McLure, W. V. Polleys, and Charles H. Higgins, were presented by title only.

The Assistant Secretary reported that, in accordance with the unanimous report of the Committee to Recommend the Award of Prizes, the Board of Direction had awarded the prizes for the year ending with the month of July, 1909, as follows:

The Norman Medal to J. A. L. Waddell, M. Am. Soc. C. E., for his paper entitled "Nickel Steel for Bridges."

The Thomas Fitch Rowland Prize to W. J. Wilgus, M. Am. Soc. C. E., for his paper entitled "The Electrification of the Suburban Zone of the New York Central and Hudson River Railroad in the Vicinity of New York City."

The Collingwood Prize for Juniors, to H. L. Wiley, Jun. Am. Soc. C. E., for his paper entitled "The Sinking of the Piers for the Grand Trunk Pacific Bridge, at Fort William, Ontario, Canada."

The Assistant Secretary announced the election of the following candidates, by the Board of Direction, on February 1st, 1910:

As Members.

Hubert Francis Daubeny Burke, Santo Domingo City, Santo Domingo.
William Grant, Lincoln, Nebr.
Francis Valentine Toldervy Lee, San Francisco, Cal.
Eric Haldorson Loe, Minneapolis, Minn.
Robert Allen McConaghy, Chinwangtao, North China.
Nils Lorentz Malmros, New York City.
William Pitt Mason, Troy, N. Y.
Stephen Halsey Meem, Bluefield, W. Va.
Marshall Morris, Jr., Louisville, Ky.
William Arthur Payne, New York City.
Gorham Andrew Taylor, Duluth, Minn.
William Roe Weidman, Glen Ellyn, Ill.

As Associate Members.

Charles Robert Adams, St. Paul, Minn.
Thomas Byrnes Brogan, New York City.
Elwyn Francis Chandler, University, N. Dak.
Alvin Sayles Cutler, Minneapolis, Minn.
William Albert Edward Doying, Washington, D. C.
Hugh Kendall Hood, Blacksburg, S. C.
Clarence Durand Howe, Huntley, Mont.
Robert Chan Johnson, Changsha, China.
Ross LeHunt Mahon, Sault Ste. Marie, Mich.

URBAN SERENUS MARSHALL, Roseville, Cal.
FREDERICK MEARS, Cristobal, Canal Zone, Panama.
LESLIE MULLER, New York City.
ROBERT J. NEWELL, Twin Falls, Idaho.
JOSEPH O'NEIL, Leavenworth, Kans.
LAWRENCE PATRICK SLATTERY, Greenville, N. C.
WILLIAM HERBERT WATT YEO, Las Cruces, N. Mex.

AS ASSOCIATES.

JESSE ALBERT CURREY, Portland, Ore.
ALBERT SOMMER, New York City.

AS JUNIORS.

HENRY CONRAD ACKEMANN, Springfield, Ill.
CHESTER ELY ATWOOD, Valier, Mont.
WILLIAM WALTER BIGELOW, Waltham, Mass.
WALTER LOUIS DUMOULIN, Cananea, Sonora, Mexico.
EDWARD FREDERIC HAMMEL, Harrisburg, Pa.
TOM HIND HUDSON HARROD, Ithaca, Mich.
HARRY PIKE LETTON, Lincoln, Nebr.
CHARLES ABNER LYERLY, JR., Gadsden, Ala.
JOHN WALDO PARET, Altus, Okla.
CHARLES JUDSON PATERSON, Oklahoma City, Okla.
THEODORE LOCHART PAUL, Providence, R. I.
LOUIS JOHN SIELING, Brooklyn, N. Y.
WARREN DUDLEY TRASK, Valier, Mont.
JAMES DEWITT WILLCOX, Denver, Colo.

The Assistant Secretary announced the transfer of the following candidates by the Board of Direction on February 1st, 1910:

FROM JUNIOR TO MEMBER.

FRANK PARSONS LANT, New York City.

FROM ASSOCIATE MEMBER TO MEMBER.

HARRIS DEHAVEN CONNICK, San Francisco, Cal.
BOYD EHLE, Scotts Bluff, Nebr.
PHILIP PATRICK FARLEY, Brooklyn, N. Y.
WILLIAM GRANVILLE GOVE, Brooklyn, N. Y.
HENRY SCUDDER JAUDON, Savannah, Ga.
GEORGE VOLNEY RHINES, Toledo, Ohio.
FRANK CUMMINGS SHEPHERD, Jackson, Ga.
EDWARD CLAYTON SHERMAN, Culebra, Canal Zone, Panama.

FROM JUNIOR TO ASSOCIATE MEMBER.

FRED EDWARD CALDWELL, Newton, N. J.
JAMES HARPER DUNCAN, Searsport, Me.

Dean Gray Edwards, Walden, N. Y.
Harry Clifford Ford, New York City.
Richard King Hale, Boston, Mass.
Leland Wesley Irish, Evanston, Ill.
Augustus Kempkey, Jr., Piedmont, Cal.
Frank Ray Lanagan, Albany, N. Y.
William Franklin Martin, Honolulu, Hawaii.
Horace Edwards Plummer, Portland, Ore.
Charles Garfield Ranney, Mohawk, N. Y.
William Adams Treadwell, Albany, N. Y.
Frank Leslie Wilcox, St. Louis, Mo.

The Assistant Secretary announced the following deaths:

Clifford Buxton, elected Member May 6th, 1885; died January 12th, 1910.

George Earl Church, elected Member November 2d, 1887; died January 5th, 1910.

Camille Stanislaus d'Invilliers, elected Member January 4th, 1888; died January 2d, 1910.

John H. Emigh, elected Member April 3d, 1901; died January 6th, 1910.

Edward Cornelius Kinney, elected Member May 3d, 1882; died January 16th, 1910.

Samuel R. Probasco, elected Member November 18th, 1868; died January 19th, 1910.

Henry Donald Whitcomb, elected Member February 21st, 1872; died January 26th, 1910.

William Wright Starr, elected Member May 1st, 1907; date of death unknown.

Adjourned.

OF THE BOARD OF DIRECTION

(Abstract)

January 19th, 1910.—The Board met, as required by the Constitution, at the House of the Society during the Annual Meeting, January 19th, 1910, at 12.40 P. M., President Bensel in the chair; Chas. Warren Hunt, Secretary, and present, also, Messrs. Andrews, Bates, Brackett, Churchill, Fanning, Kimball, Knap, Loomis, Loweth, Macdonald, McDonald, Pegram, Schneider, Stearns, Sumner, Talbot, and Thompson.

The President announced the first business of the Board to be the election of a Secretary.

Mr. Hunt retired.

Charles Warren Hunt was placed in nomination for Secretary for the ensuing year.

Nominations were closed.

The President was directed to cast a ballot for all of those present in favor of Charles Warren Hunt for Secretary.

The President declared Mr. Hunt elected Secretary.

Mr. Hunt was recalled and resumed his duties.

The following Standing Committees of the Board were appointed:

Finance Committee: George H. Pegram, Charles S. Churchill, George A. Kimball, Horace Loomis, William G. Wilkins.

Publication Committee: Charles L. Harrison, Horace Andrews, William E. Belknap, Francis Lee Stuart, Emil Swensson.

Library Committee: George W. Kittredge, Dexter Brackett, John T. Fanning, Chas. Warren Hunt, Hunter McDonald.

Past-President Onward Bates was appointed to represent the Society on the John Fritz Medal Board of Award.

The following report of the Committee appointed to Recommend the Award of Prizes was received:

"CHICAGO, Dec. 31, 1909.

"CHAS. WARREN HUNT, Secy.,
"American Society of Civil Engineers,
"220 W. 57th Street,
"New York, N. Y.

"DEAR SIR:—

"The Committee of the Society appointed to recommend the award of prizes for the year 1909 respectfully report unanimous recommendations as follows:

"1.) NORMAN MEDAL: We recommend the award of the Norman Medal to paper No. 1103, 'Nickel Steel for Bridges,' by J. A. L. Waddell.

"2.) ROWLAND PRIZE: We recommend the award of the Rowland Prize to paper No. 1079, 'Electrification of the Suburban Zone of the N. Y. C. & H. R. R. R. in New York,' by W. J. Wilgus.

"3.) COLLINGWOOD PRIZE: We recommend the award of the Collingwood Prize to paper No. 1094, 'Sinking Piers for the Grand Trunk Pacific Bridge at Fort William, Ontario, Canada,' by H. L. Wiley.

"Hoping that these decisions may meet with the approval of the membership of the Society.

"Very truly yours,

"CHAS. B. BALL,
"*Chairman*,
"OTTO VON GELDERN,
"ARTHUR PEW."

The recommendations of the Committee were adopted and the awards made in accordance therewith.

Adjourned.

February 1st, 1910.—President Bensel in the chair; Thomas J. McMinn, Assistant Secretary, acting as Secretary, and present, also, Messrs. Andrews, Belknap, Brackett, Loomis, Macdonald, Pegram, Roberts, Schneider, Stearns, Stuart, Thompson, Wilkins, and Williams.

A request from the San Francisco Association of Members of the American Society of Civil Engineers, in regard to amendment to its Constitution, providing that its Annual Meeting shall be held in December, was approved.

Ballots for Membership were canvassed, resulting in the election of 12 Members, 16 Associate Members, 2 Associates, and 14 Juniors, the transfer of 8 Associate Members to the grade of Member, 1 Junior to the grade of Member, and 13 Juniors to the grade of Associate Member.

Applications were considered, and other routine business transacted.

Adjourned.

REPORT IN FULL OF THE FIFTY-SEVENTH ANNUAL MEETING, JANUARY 19th and 20th, 1910.

Wednesday, January 19th, 1910.—President Bates in the Chair; Charles Warren Hunt, Secretary; and present, also, about 245 members. Meeting cal to order.

The President.—The meeting will come to order. Under the Constitution of the Society, the ballot for the election of officers must be kept open until twelve o'clock, noon. Ballots will be received until that time; but, in order to facilitate the counting, I will name as tellers now: Messrs. Horace J. Howe, W. J. Carter, and L. S. Cowles; are those gentlemen present? Tellers appointed

The Secretary.—I might say that the tellers will find the ballots on the third floor, and all the available people on the staff ready to help in opening and counting them.

The President.—I will ask the Secretary to read the Report of the Board of Direction to the Society. Report of t Board of Direction

The Secretary read the Report of the Board of Direction.*

The President.—Will you read the reports of the Secretary? Report of t Secretary

The Secretary read his Report.†

The Secretary.—Mr. President, it might be interesting to call attention to the facts shown in the balance sheet. According to it, if we omit the items of furniture, publications on hand, and value of the library (on which it might be difficult to realize), the actual assets of the Society, which could be turned into cash, on December 31st, 1909, were $354 619.51.

In a circular issued by the Board of Direction, May 25th, 1895, at the time the building of a new house was contemplated, the available assets at that time were stated to be $64 500.

The present estimated value of the Society's property is believed to be extremely conservative, but nevertheless it appears that in less than fifteen years the assets of the Society have been increased by about $290 000.

The President.—I call for the Treasurer's Report. Report of t Treasurer

The Treasurer read his Report.‡

The President.—Unless there is some objection, these reports will be received and filed. The next business in order is the appointment of seven members of the Nominating Committee, one from each of the geographical districts, and I will ask the Secretary to read the list of suggestions from members in those districts. Nominatii Committe

The Secretary.—Mr. President, I beg to report the receipt of 1 366 final suggestions from the Corporate Membership for members of the Nominating Committee, or 31% of the total voting membership.

* See *Proceedings*, Vol. XXXVI, p. 11 (January, 1910).

† See *Proceedings*, Vol. XXXVI, p. 18 (January, 1910).

‡ See *Proceedings*, Vol. XXXVI, p. 20 (January, 1910).

Nominating Committee (continued).

In District No. 1 the number of suggestions received was 261. Mr. James C. Meem, Brooklyn, N. Y., has received 140 votes; Mr. James H. Brace, New York City, 64; Mr. Charles E. Gregory, Mt. Kisco, N. Y., 46; Mr. Herbert A. Warren, New York City, 6; and Messrs. Joseph H. O'Brien, Yonkers, N. Y., C. J. Parker, New York City, Albert I. Frye, Brooklyn, N. Y., Henry W. Hodge, New York City, and George E. Low, Maplewood, N. J., one vote each.

On motion, duly seconded, James C. Meem, M. Am. Soc. C. E., was appointed a member of the Nominating Committee for District No. 1.

The Secretary.—From District No. 2, 129 suggestions have been received, as follows: Mr. J. R. Worcester, Boston, Mass., 78; Mr. Leonard Metcalf, Boston, Mass., 16; Mr. Harrison P. Eddy, Boston, Mass., 15; Mr. F. H. Fay, Boston, Mass., 12; Mr. H. A. Miller, Boston, Mass., 7; and George F. Swain,* Boston, Mass., 1.

On motion, duly seconded, J. R. Worcester, M. Am. Soc. C. E., was appointed a member of the Nominating Committee for the Second District.

The Secretary.—From District No. 3, 244 votes have been received, as follows: Mr. Henry C. Allen, Syracuse, N. Y., 94; Mr. Charles J. Tilden, Ann Arbor, Mich., 71; Mr. A. H. Hogeland, St. Paul, Minn., 18; Mr. C. L. Crandall, Ithaca, N. Y., 15; Mr. E. E. Haskell, Ithaca, N. Y., 10; Mr. Henry Holgate, Montreal, Que., Canada, 10; Mr. C. A. P. Turner, Minneapolis, Minn., 7; Mr. George L. Wilson, Minneapolis, Minn., 5; Mr. Charles F. Stowell, Albany, N. Y., 5; Mr. T. H. Mather, Syracuse, N. Y., 5; Mr. J. E. Schwitzer, Winnipeg, Man., Canada, 2; Louis H. Knapp, Buffalo, N. Y., 1; and William B. Landreth, Schenectady, N. Y., 1.

Both Messrs. Henry C. Allen and Charles J. Tilden were duly nominated, and a rising vote was taken, resulting in 78 votes for Mr. Allen, and 35 votes for Mr. Tilden.

The President declared Henry C. Allen, M. Am. Soc. C. E., a member of the Nominating Committee representing District No. 3.

The Secretary.—The total number of votes received from District No. 4 was 255, as follows: Mr. J. E. Greiner, Baltimore, Md., 140; Mr. R. L. Humphrey, Philadelphia, Pa., 96; Mr. C. C. Rose, Scranton, Pa., 15; Mr. Alexander Mackenzie, Washington, D. C., 1; Mr. James H. Harlow, Darlington, Md., 1; Mr. A. M. Quick, Baltimore, Md., 1; and Mr. H. M. Wilson, Washington, D. C., 1.

On motion, duly seconded, J. E. Greiner, M. Am. Soc. C. E., was appointed a member of the Nominating Committee for the Fourth District.

The Secretary.—From District No. 5, 165 votes have been received, as follows: Mr. Isham Randolph, Chicago, Ill., 120; Mr. F. C. Osborn, Cleveland, Ohio, 26; Mr. G. H. Bremner, Chicago, Ill., 18; Mr. William M. Hughes, Chicago, Ill., 1.

* Mr. Swain is ineligible.

On motion, duly seconded, Isham Randolph, M. Am. Soc. C. E., was elected a member of the Nominating Committee for District No. 5.

THE SECRETARY.—From District No. 6, 121 votes have been received, as follows: Mr. Richard Montfort, Louisville, Ky., 43; Mr. H. M. Marshall, Vicksburg, Miss., 37; Mr. W. M. Hall, Parkersburg, W. Va., 26; Mr. P. H. Norcross, Atlanta, Ga., 5; Mr. J. F. Coleman, New Orleans, La., 2; Mr. William H. Balch, Santo Domingo, W. I., 2; Mr. W. H. Courtenay, Louisville, Ky., 1; Mr. T. G. Dabney, Clarkesdale, Miss., 1; Mr. T. A. Corry, Lima, Peru, 1; Mr. Julian Kendrick, Birmingham, Ala., 1; Mr. J. J. Knoch, Fayetteville, Ark., 1; Mr. J. E. Sirrine, Greenville, N. C., 1.

On motion, duly seconded, Richard Montfort, M. Am. Soc. C. E., was elected a member of the Nominating Committee for the Sixth District.

THE SECRETARY.—The total number of votes from District No. 7 was 191, as follows: Mr. R. H. Thompson, Seattle, Wash., 80; Mr. J. D. Galloway, San Francisco, Cal., 68; Mr. C. E. Fowler, Seattle, Wash., 29; Mr. D. C. Henny, Portland, Ore., 2; Mr. J. L. Campbell, El Paso, Tex., 1; Mr. Frank C. French, Salt Lake City, Utah, 1; Mr. T. W. Jaycox, Denver, Colo., 1; Mr. J. B. Lippincott, Los Angeles, Cal., 1; Mr. J. W. McConnell, Denver, Colo., 1; Mr. C. D. Marx, Palo Alto, Cal., 1; Mr. D. W. Ross, Oakland, Cal., 1; Mr. Edwin Hall Warner, Los Angeles, Cal., 1; Mr. Frank Washburn,* Nashville, Tenn., 1; Mr. John C. Whistler, Portland, Ore., 1; Mr. Louis C. Hill, Phœnix, Ariz., 1; and Luther Wagoner, San Francisco, Cal., 1.

On motion, duly seconded, R. H. Thompson, M. Am. Soc. C. E., was elected a member of the Nominating Committee for District No. 7.

Report of Special Committee on Columns and Struts.

THE PRESIDENT.—We will now hear the report of the Special Committee on Steel Columns and Struts, of which Mr. Bowman is Chairman.

AUSTIN L. BOWMAN, M. AM. SOC. C. E.—Mr. President, the report of this Committee was published in the December, 1909, *Proceedings*, and I will request the Secretary to read it, if he will.

The Secretary read the Report of the Special Committee on Steel Columns and Struts.†

THE PRESIDENT.—You have heard this report, gentlemen. It is open for discussion.

THE SECRETARY.—Mr. President, I have a brief written communication on this subject from a member of this Society in discussion of this report.

THE PRESIDENT.—Will you please read it, Mr. Secretary?

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* Ineligible.

† See *Proceedings*, Vol. XXXV, p. 519 (December, 1909).

Discussion on Report of Special Committee on Columns and Struts.

DISCUSSION ON THE PROGRESS REPORT OF THE SPECIAL COMMITTEE ON STEEL COLUMNS AND STRUTS.

"In this Progress Report the Committee has brought together many column tests recorded heretofore, and has sought to prepare the way for further study and analysis by adjusting the results to a uniform grade of metal, for which they have chosen that grade which has an ultimate tensile strength of 60 000 lb. per sq. in. For this purpose they assume that the ultimate strengths of different grades of metal in tension and compression are proportional.

"It is not the intention of the writer to criticize the latter assumption, but to offer objection to the manner of its application.

"The Committee has apparently lost sight of the fact that the stresses in a column are a combination of compression and bending, and that, as the length ratio $\left(\frac{l}{r}\right)$ increases, the bending stresses become more and more dominant, until at last the compression disappears, and the column passes under the law represented by Euler's equation, $\frac{P}{A} = \frac{E\,a}{\left(\frac{l}{r}\right)^2}$.

"The only physical properties embraced in this equation are, the factor, a, representing the form of end bearing, and the modulus of elasticity, E, a factor which is practically constant for all grades of iron and steel. The variations in this factor, as found for different grades of steel, are not greater than are frequently found for different specimens of the same steel.

"This fact being recognized, it follows that, within the field of the higher length ratios, where Euler's equation applies, all grades of steel, *ceteris paribus*, give similar results; and in the field of the shorter length ratios the different grades of metal give results converging with increasing length ratios.

"Now, the Committee has applied the ratio, found as stated, to all tests in the respective groups, regardless of the value of $\frac{l}{r}$ in each instance; but that ratio is applicable only at the axis of abscissas $\left(\frac{l}{r} = 0\right)$, and the adjustment should diminish to 0 at that value where Euler's equation begins to apply. Hence, the method adopted by the Committee will be misleading and deceptive by applying unduly large adjustments to tests with the larger values of $\frac{l}{r}$.

"The value of $\frac{l}{r} = 0$ will vary with the form of end bearing, and the grade of material, and is indeterminate at this stage of the Committee's work, unless they assume to be correct, either the equation

heretofore proposed by the writer, or that of the late J. B. Johnson, M. Am. Soc. C. E., or perhaps some other; but, if it is the intention that the work of this Committee shall be wholly independent of previous investigations and studies, such assumption is scarcely in order.

"But the fact that the correction for adjustment must diminish to 0 at some definite value of $\frac{l}{r}$ in each group of tests cannot be avoided, and any conclusions based on the uniformly applied ratios of adjustment will be vitiated thereby.

"It seems best to call attention to this point now before the work of the Committee has progressed to the point of definite conclusions.

"THOS. H. JOHNSON."

JOHN F. O'ROURKE, M. AM. SOC. C. E.—Mr. Chairman, in the report of the Committee, it is pointed out that the objection to tests of large sizes is the cost. I would like to make a suggestion in regard to that. I know of one building, which has only been erected about twelve years, which will be torn down, and there are a great many others which have been found too small for the value of their sites, and have been torn down. The material in those buildings is just as good for tests now as it would have been when they were built, and the loss of value caused by the test is very little. As such columns always represent special construction and special design, they have only scrap values, and are almost as good after the test as before. I just call the attention of the Committee to that fact; perhaps it may help their tests along.

THE PRESIDENT.—Is there any other discussion on this report? What will this meeting do with the Progress Report?

JAMES OWEN, M. AM. SOC. C. E.—I move that it be referred back to the Committee, and the Committee continued.

THE PRESDENT.—Is the motion seconded?

THE SECRETARY.—The Secretary would like to know what to do with the report, as far as the printing is concerned. The report is not complete as printed in the *Proceedings,* there being one diagram which was not available at the time the report was printed.

MR. OWEN.—My motion would cover that.

THE SECRETARY.—That it be printed in the *Transactions?*

THE PRESIDENT.—Is Mr. Owen's motion seconded?

Motion duly seconded.

THE PRESIDENT.—It is moved and seconded that the Report of the Special Committee on Steel Columns and Struts be printed in the *Transactions,* and referred back to the Committee, and the Committee continued. Any discussion?

A. N. TALBOT, M. AM. SOC. C. E.—I move, to amend, that it be accepted as a report of progress, that it be printed, and the Committee continued.

Report of Special Committee on Columns and Struts (continued).

Mr. Owen.—I will accept that.

The President.—You have heard the motion, gentlemen: I will call for the amendment first.

Mr. Owen.—I will accept the amendment.

The President.—The amendment is accepted. All those in favor of the motion, which is that the report of the Committee be accepted and printed, and the Committee be continued, will signify by saying "aye"; contrary, "no." The motion is carried.

Report of Special Committee on Bituminous Materials for Road Construction.

The Report of the Special Committee on Bituminous Materials for Road Construction.

The Secretary.—Mr. W. W. Crosby is the Chairman of that Committee.

The President.—Is Mr. Crosby present?

In the absence of Mr. Crosby, the Secretary read the Report of the Special Committee on Bituminous Materials for Road Construction.*

The President.—Is there any discussion on this report? What will you do with it?

S. Whinery, M. Am. Soc. C. E.—I move that the report be received and printed, and the Committee continued.

Mr. Owen.—I second the motion.

The President.—Any discussion? All those in favor of the motion, which is that the report be received and printed in the *Transactions*, and the Committee continued, will signify it by saying "aye"; contrary, "no." The motion is carried.

Report of Special Committee on Rail Sections.

The President.—I will ask the Secretary to read the Report of the Special Committee on Rail Sections.

The Secretary.—Mr. President, the Secretary has received the following report:

PROGRESS REPORT OF SPECIAL COMMITTEE ON RAIL SECTIONS.

November 30th, 1909.

The American Society of Civil Engineers,

Gentlemen:—In order to refresh the memory of the members of the Society, your Special Committee begs to recapitulate the instructions under which it was appointed in 1902.

1. To report upon the results obtained in the use of rails of the sections presented to the Society in Annual Convention, August 2d, 1893, by a special committee appointed for that purpose;

2. To report whether any modification of any of said sections is advisable, and, if so, to recommend such modification;

* See *Proceedings*, Vol. XXXV, p. 517 (December, 1909).

3. To report upon the recognized practice as to chemical composition and mechanical treatment used in the manufacture of rails, and the manner of inspection of the same;

4. To report upon the advisability of the establishment of a form of specification covering the manufacture and inspection of rails;

5. If found advisable, to recommend a form of specification for the manufacture and inspection of rails.

The work on rail sections and specifications is progressing on the lines laid down in our report of December 18th, 1908. The work of the Committee during the past year has been chiefly confined to keeping in touch with the railroads and the other engineering associations, and the U. S. Government tests. The general use of the cardinal principles submitted in your Committee's report of December 6th, 1907, still continues as stated in last year's report.

During the past year a standard drop testing machine has been adopted which results in uniform practice at all the mills, and is of great value in giving information to aid the Committees in their study and analysis of rail failures.

The collection of data and statistics as to rail failures and rail wear by the various railroads, is now generally being made on uniform blanks recommended by the American Railway Engineering and Maintenance of Way Association, and is affording valuable information with regard to the respective merits of the several rail sections and specifications now in use. These blanks, however, have not been in use long enough to give sufficient data to warrant your Committee in making a final report at this time, either to recommend the adoption of a series of rail sections for all railroads of the United States or for the chemical composition or mechanical treatment of rails; and we would therefore ask that this be accepted as a progress report, and the Committee continued, in order that we may make a further study by continuing the investigations of the manufacture of rails and their use under the actual conditions of traffic.

Respectfully submitted,

Jos. T. Richards, *Chairman,*
Robert W. Hunt, *Secretary,*
C. W. Buchholz,
E. C. Carter,
S. M. Felton,
John D. Isaacs,
Richard Montfort,
H. G. Prout,
Percival Roberts, Jr.,
Geo. E. Thackray,
Edmund K. Turner,
Wm. R. Webster.

Report of Special Committee on Rail Sections (continued).

THE PRESIDENT.—Is there any discussion on this Report of the Special Committee on Rail Sections? What shall be done with the report?

It was duly moved and seconded that the report be accepted.

THE PRESIDENT.—It is moved and seconded that the Report of the Special Committee on Rail Sections be accepted. Any discussion? All those in favor of the motion will signify by saying "aye"; contrary, "no." The motion is carried.

Report of Special Committee on Engineering Education.

THE PRESIDENT.—The Report of the Special Committee on Engineering Education.

DESMOND FITZGERALD, PAST-PRESIDENT, AM. SOC. C. E.—I have a Progress Report of that Committee, Mr. President, but, before reading it, I would like to say a word on these annual reports, if I am not out of order.

THE PRESIDENT.—We will be pleased to hear you.

MR. FITZGERALD.—In common with some other men whom I see on this floor, I have completed my forty-second year of service in the Profession, and perhaps I may be allowed to say a word as to how some of these reports struck me when I was sitting here this morning. I will take but a moment.

THE PRESIDENT.—You may have all the time you want, sir.

MR. FITZGERALD.—I remember very well, when we thought, as a Society, that we had an extravagant house in the old house on Twenty-third Street, and the question was whether or not we could ever run it, as a Society. Then we came into this sumptuous hall, and we wondered whether we could ever run this. To-day you have heard of our large surplus, which is very gratifying. There is no doubt that the Society is getting rich, but that brings danger with it. Sometimes, you know, a man who stands temptation very well in poverty, does not stand it so well when he falls into a fortune.

I think the great thing that we have to be proud of, as a Society, is the wonderful advance in the Profession itself, and in the character of the papers which have been presented in the last few years. That has impressed itself very deeply on my mind.

I remember when the Norman Medal was awarded, twenty or thirty years ago, for papers that were read before the Society; they were considered to be wonders, and the question was whether the Society would ever again see such papers. Well, the papers that we have had recently, which have received the Norman Medal and the Thomas Fitch Rowland Prize, leave no question as to a general advance all along the line. The Profession is holding its own and going ahead. I, for one old fogy, am absolutely satisfied.

Now, for this Progress Report:

REPORT OF THE SPECIAL COMMITTEE ON ENGINEERING EDUCATION.

The Committee on Engineering Education has continued its studies and investigations in connection with this important subject during the past year and desires to report the following progress:

As already reported, your Committee has worked in connection with, and as forming a part of, the larger Committee of 15 members, representing business colleges and societies.

It is desirable before deciding in what direction Engineering Education can be improved to ascertain first what is being done by the various educational centers in the United States in the direction of technical instruction. After long conferences it was decided to make a beginning with the subject of Electrical Engineering, as this course could in some ways be more clearly defined than many of the other divisions of the profession.

All the studies were grouped under seven general heads, as follows:

Mathematics,
Physics and Chemistry,
Humanistic,
Drawing,
Shopwork,
General Engineering,
Electrical Engineering.

Each of these groups contained from 4 to 17 studies. Through the kindness of the Carnegie Foundation, a very extensive set of tables was prepared representing the work of 77 colleges and technological schools. These tables have been analyzed and the semester hours in each half year of the four years devoted to these studies have been classified in the case of some of the principal engineering institutions. The Carnegie Foundation has agreed to continue the work in the direction of Civil and Mechanical Engineering, as taught in 16 institutions. Tables are now in process of preparation for these courses, and, when ready, the Carnegie Foundation is to collect the data from the institutions selected.

It is hoped that, when this information is obtained and analyzed, the first step in the Committee's work will be so far advanced as to indicate a possibility of valuable results.

Desmond FitzGerald,
B. M. Harrod,
Onward Bates,
Daniel W. Mead,
Charles Hansel.

Mr. FitzGerald.—There is no doubt that this subject of Engineertion Education is attracting very wide interest, but there are many

Report of Special Committee on Engineering Education (continued).

cranks in this world; they are necessary, and a good thing, and I believe in them, but the number of theories in regard to the revolutions that can be made in Engineering Education is wonderful. Many of the suggestions are of great value; for instance, at the end of the first year in a technical school is it better for a student to leave and go into actual practical work for one year, as has been suggested by a very prominent member of the Profession, and then go back and finish his other three years, or is it better to work more along on the technical line, rather than the practical, or is it better to increase the humanistic studies?

Now, all these things are very interesting, but it will take a long time to find out whether we can really suggest any improvement on the present methods. I think the thing that we started to do, to find out first what the technical schools are actually doing in this country, what they are teaching, and then what the average is, is very valuable as a first step.

Now, it has required about two years to take this first step. We have been a year collecting these tables, which are voluminous. I would like to have any gentleman here who thinks he has a really valuable suggestion for improving Engineering Education put it on paper and send it to the Committee so that we may have as many ideas as possible when we come to work out the theoretical part; but it is a very dangerous thing for any scientific body of men to recommend improving the present methods of education unless the recommendations are based on pretty solid foundations.

The President.—Is there any discussion on this Report of the Special Committee on Engineering Education? What shall be done with it?

David Molitor, M. Am. Soc. C. E.—I move that it be accepted as a Progress Report, and the Committee continued.

Motion duly seconded.

The President.—Any discussion of this motion? All those in favor of the motion will signify by saying "aye"; contrary, "no." The motion is carried.

Report of Special Committee on Uniform Tests of Cement.

Report of the Special Committee on Uniform Tests of Cement.

Richard L. Humphrey, M. Am. Soc. C. E.—The report was sent to the Secretary to be read.

The President.—Will the Secretary kindly read it?

The Secretary read the report, as follows:

PROGRESS REPORT OF SPECIAL COMMITTEE ON UNIFORM TESTS OF CEMENT.

To the President and Members of the
American Society of Civil Engineers:

Your Special Committee on Uniform Tests of Cement begs to report that during the year it has arranged with the Ottawa Silica

Company of Ottawa, Illinois, for the preparation and delivery of Standard Ottawa Sand at the price of $0.02 per pound, F. O. B. cars Ottawa, Ill. This Company now has on hand an ample stock of sand for promptly filling all orders.

The Committee has under consideration with the Engineer Commission of the United States Army certain suggested modifications in the uniform methods of tests, and asks to be continued.

Respectfully submitted on behalf of the Committee.

George S. Webster, *Chairman,*
Richard L. Humphrey, *Secretary.*

The President.—Is there any discussion of this Report?

Alfred Noble, Past-President, Am. Soc. C. E.—Mr. Chairman, I am not fully in accord with the conclusions of the Committee, and I will hand to the Secretary a Minority Report, which I will ask him to read.

Minority Report, Special Committee on Uniform Tests of Cement.

The Secretary read the Minority Report, as follows:

MINORITY REPORT.

To the American Society of Civil Engineers:

The undersigned, a member of the Special Committee on Uniform Tests of Cement, begs leave to submit the following as a minority report:

The first report of the Committee, embracing rules and methods suggested for testing cement, was submitted to the Society Jan. 21st, 1903. From time to time these rules have been amended in minor respects, the last changes having been reported at the Annual Meeting held Jan. 20th, 1909.

These amendments merely perfect the methods proposed seven years ago, without changing them in any important degree.

From year to year the Committee has reported that various topics were under examination and study, and has asked for further time. Eight topics were referred to in the progress report at the Annual Meeting held Jan. 20th, 1904. A year later the Committee stated that "the investigations now in progress have not advanced sufficiently to reach definite conclusions and your Committee * * * is unable to present a final report at this time and it asks therefore that it be continued." This was also the condition and the recommendation submitted to the Society a year later. At the Annual Meeting held Jan. 16th, 1907, a few changes in the rules for testing, which experience had shown to be advisable, were reported. A year later, Jan. 15th, 1908, several slight changes in phraseology were reported, and five new topics were formulated, to be taken up during the year.

Minority Report, Special Committee on Uniform Tests of Cement (continued).

At the Annual Meeting of Jan. 20th, 1909, a revised edition of the rules was submitted, and the five topics mentioned the year before were again referred to as under investigation.

During the period before 1903, when the methods reported at the Annual Meeting of that year were under study, the Committee held frequent meetings, the methods were carefully tested by all or nearly all of the members, and agreement reached in all important respects. The work done consisted mainly in bringing the matter of Cement Testing up to date. Some of the details needed further trial, and a final report at that time would have been premature.

During the last seven years some doubtful points have been cleared up, and it is believed the methods are now workable in every respect. Meetings of the Committee have become less frequent, and during the last three or four years have occurred only once or twice a year. This has not been from want of interest in the subject, but simply because there was no need for more.

Since the formulation of its first report the Committee has undertaken two distinct lines of work. The first was the perfecting of the rules so that the methods recommended might represent the best state of the art of testing at the time; the undersigned believes this has been accomplished. The second line of work has been the advancing of the art of testing by continuous investigation; the undersigned submits the record as showing that the results have not been successful. It should not be expected that a Committee composed of members located at points widely distant from each other can be efficient for investigations. Such work requires the concentrated attention of individuals with properly equipped laboratories at their disposal, and substantial advance in methods will require years of time because cement mortars require a long time to mature and a large number of tests to justify conclusions.

There can be no doubt that from time to time better methods for testing will be developed; the undersigned believes, however, that the function of such a Committee as the present one is fully performed when the subject assigned to it is brought fully up to date, and is convinced that the Committee should now make such slight changes in the rules as eliminate expressions implying indefinite continuance, and submit the result as a final report at the earliest date practicable.

ALFRED NOBLE.

THE PRESIDENT.—We have Majority and Minority Reports of this Committee.

MR. HUMPHREY.—Mr. Chairman, I would like to say that there is a feeling on the part of the Committee that the remarks of Mr. Noble are quite correct, and I think it is fair to say that a great many of us feel that the Committee should be discharged, but there has also been a feeling that it might finish its work and make it more complete, and

while it is true that the Committee has not been able to make as definite progress from year to year as would seem to be desirable, nevertheless, it is a fact that the conditions under which the Committee worked were rather difficult.

It is certainly the intention of the Committee to recommend that it be discharged at an early date, and I think it is the feeling of the Committee that at the next Annual Meeting the Committee could properly present its final report. I think that all that Mr. Noble has said is quite true, and I would move, Mr. President, that the Committee be continued for the present.

The President.—Is there a seconder to that motion? Would it be well to have these reports printed?

The Secretary.—They will be printed in connection with this meeting, a report in full.

Mr. Whinery.—There seems to be some difference of opinion as to what the proceeding should be in reference to this Committee. It seems to be generally agreed that a final report might be proper, in time for the next Annual Meeting, and there seems to be a desire that it should be prepared and submitted at that time.

I wish to offer an amendment to the motion, to the effect that the Committee be continued and directed to render a final report at the next Annual Meeting.

Mr. Humphrey.—I accept that amendment, Mr. President.

The President.—The amendment is accepted. Therefore the motion is that the Committee be continued and directed to make a final report at the next Annual Meeting. Any discussion of this motion? All those in favor of it will signify by saying "aye"; contrary, "no." The motion is carried.

Report of Special Committee on the Metric System.

The Report of the Special Committee on the Status of the Metric System.

Mr. Molitor read the Report of the Special Committee on the Status of the Metric System, as follows:

REPORT OF SPECIAL COMMITTEE ON THE METRIC SYSTEM.

To the Officers and Members of the
American Society of Civil Engineers:

Your Committee has been continued during the past year to meet any questions that might arise, and to give proper and respectful attention to such relevant information as might be presented for consideration.

Up to the present time the only questions and data that have been received are two-fold:

1. Those relating to the unceasing debate as to the merits and demerits of the Metric System.

Report of Special Committee on the Metric System (continued).

2. And those relating to its extended applications appearing here and there among the signs marking the progress of the times.

The question of merit does not seem properly to come within the jurisdiction of the duties assigned to your Committee, which was appointed merely to collect data and present a report on the "present status of the Metric System in the United States."

The matter of status was discussed in a report submitted to the Society over a year ago, to which your Committee again invites special attention, believing that this report still represents the status of the subject. See *Proceedings* of October, 1908.

There is little to be added to that report except to note a slight gain in favor of the Metric System, while most of the antagonism seems to resolve itself into an exposition of ignorance and lack of appreciation for anything which savors of progress, or is dependent entirely on commercial conditions.

Your Committee believes that all obtainable co-operation should be solicited to further and promote education in the lowest grades of all schools; and that a copy of its first report should be sent to each member of Congress and of the N. Y. State Legislature with a letter or circular calling attention to the limited opportunity existing in this country for the coming generation to learn the Metric System of weights and measures.

There appearing no immediate need for any further reports on the question of status, your Committee respectfully requests that it be discharged.

JAN. 13, 1910.

STACY B. OPDYKE, JR., *Chairman.*
DAVID MOLITOR.

THE PRESIDENT.—Is there any discussion of this Report of the Special Committee on the Metric System?

H. M. WILSON, M. AM. SOC. C. E.—Mr. President, do I understand that there is a definite motion before the meeting in connection with this report, to the effect that this Society shall memorialize Congress and the State Legislature on the subject? That is the impression that I gather from the report.

THE PRESIDENT.—I will ask Mr. Molitor to answer that.

MR. MOLITOR.—I think the intention of the report is merely to let the Society take such action as it sees fit. We merely recommend that copies of that report be sent to the Congressmen and also to the members of the State Legislature.

THE PRESIDENT.—What shall be done with this report?

MR. FITZGERALD.—Mr. President, was it not our Society that in one night changed the whole standard time of the country?

THE SECRETARY.—Not in one night.

Mr. FitzGerald.—I was under the impression that the Committee that we had on that subject made that recommendation, and one morning we woke up and found that we had to set our watches back or set them forward, as the case might be.

It seems to me that we might suggest to Congress to introduce the metric system in this country, and make a report to that effect to this Society, and not send a partial report to the members of the New York State Legislature at all.

Mr. Wilson.—Mr. FitzGerald's remarks embolden me to state what was in my mind. Some ten years ago, when there happened to be a committee in Congress to which this matter of the metric system was referred, I was a member of a committee, appointed by the Washington Academy of Sciences, to consider the adoption of the metric system in the United States, and to appear before the committee; and I must acknowledge that the experience then gained in the presence of a friendly committee was such that it would make me feel rather alert in case any such suggestion should arise from this Society to induce or recommend to the Congress of the United States the adoption of the metric system in the United States in one day, as I think we tried to do in regard to standard time.

I do not believe that this Society is in a position to take any very definite steps toward presenting this to Congress, friendly as I am to the adoption of the metric system in the United States.

George F. Swain, M. Am. Soc. C. E.—Mr. President, if I am correctly informed, the Committee of the Institute of Electrical Engineers has recently decided to recommend that, in the publications of the Institute, wherever figures are used, the corresponding metric figures should also be expressed in parentheses. I have felt, in regard to the metric system, exactly as Mr. Wilson has expressed himself. I felt that it was not wise to try to push it faster than it would naturally grow, but the idea does seem to me to be a good one, and at least worthy of some consideration, whether it would be well for us, in our *Proceedings,* to endeavor to help a popular understanding of the metric system by adding metric figures where the usual figures are used. I do not want to make a motion to that effect, but I should like to have somebody discuss the matter from that point of view.

Mr. Molitor.—Mr. President, I understand there is a rule in this Society that all drawings attached to papers must be supplied with the metric scale, in addition to the ordinary scale. Am I correct?

The Secretary.—No, sir.

Mr. Molitor.—I guess I have confused it with the requirement of the Association of Engineering Societies. I know they require it there, and I thought it was the same with our publications. However—to return to the report—it is not the intention of the Committee to force the metric system upon anybody, and the report was simply a

Report of Special Committee on the Metric System (continued).

review of the present status of the case, and the present report was simply to advocate the promulgation of that report, with the end in view that the people of the United States might have some better facilities to become familiar with what we mean by the metric system.

There is gross ignorance in the average American assembly regarding this very important subject, and it is a matter for public education. If we wish to see any progress in the direction of introducing the system, it must come by gradual education, and your Committee has realized that fact, and for that reason we ask simply that the report be sent to the members of Congress for their information, and we only advocate in that report such measures as might lead up to spreading the educational features for the benefit of the community at large.

Mr. O'Rourke.—Mr. Chairman, I am very much in favor of education of every kind. I see no reason why we should not educate the people of the United States on the metric system, particularly Congress. We have one Congressman here, who is so very modest at times that he refuses to commit himself, even on that subject, and I request that Major Wiley tell us what he thinks about the knowledge of Congressmen on the metric system.

W. H. Wiley, M. Am. Soc. C. E.—Of course, you can send the arguments, *pro* and *con,* to Congress. I do not like to go back on my own party, but I will say that nine out of ten will not read them, and nine and three-quarters will not understand them.

When the matter came up before the Congressional Committee, as Mr. Wilson has reported to-day, and as the facts show, the arguments went along for several days. Prominent engineers from all over the country went before the Committee. The Committee decided that it could not be adopted. I do not think the Society should waste its money in sending the reports forth, for I think they would be of no avail.

Mr. Wilson.—Before entirely dropping this subject, because it is an interesting one to me, and I think to the members of this Society, and for their guidance in connection with the feature of the subject raised by Professor Swain, namely the adoption by this Society of the scale of measures, I think that at the time of which I spoke, the occasion when the Geological Survey, in connection with its topographic maps, of which several thousand separate sheets are now published, decided that, in the same direction—for educational purposes and because European countries were familiar with the metric system—it was desirable that the scales be expressed also in the metric system. That has been done for many years now.

More recently, in connection with the meeting of a technical committee, the general supply committee prepared specifications for the purchase of all sorts of things, from a needle to a locomotive, that committee being charged with the duty of recommending the character

of the tests to be made with regard to such materials as require tests, this question of the metric system came up again, and, a few months ago, it was agreed that we should endeavor to introduce metric measures in certain of the specifications.

Our enthusiasm, however, was gradually dampened, as we came in contact with one bureau chief after another, until ultimately we found that practically the only thing that could be accomplished was an inclusion of metric weights and measures in connection with the development of certain lines of chemicals for the use of various bureaus which have to do with the supervision of the Pure Food and Pure Drugs Act; and there we found that we could not call for samples to be delivered in metric measures, because the various products are all in English measures, therefore, we could only ask for a separate list to accompany the bids.

The President.—What shall be done with this Report?

Mr. Swain.—I move that the Report of the Committee be accepted and the Committee discharged. That does not mean that copies of the Report shall be sent to anybody.

F. S. Curtis, M. Am. Soc. C. E.—I move that the Report be accepted with the exception of that part that requires the Society to send notices to Congress and the Legislature of the State; with that exception, I move that it be accepted and the Committee discharged.

The President.—That is an amendment to Professor Swain's motion.

Motion duly seconded.

Mr. Whinery.—Mr. President, the first motion was to accept this Report and to discharge the Committee. Now, that covers all the purpose. There is nothing in that Report, beyond a recommendation of the Committee, binding this Society to take any action; in fact, any such action as is recommended in that Report would be illegal and improper unless it were definitely moved and decided by this meeting to take the action recommended by the Committee.

It seems to me that the amendment is at least unnecessary.

Mr. Curtis.—If I understand it, Mr. President, that Report includes itself a part of the Report. If it only recommends, and the Society can only do what it likes, all right, but if you accept the Report as a whole, I understand that the Society is practically obliged to send out this Report. If I am wrong——

Mr. Swain.—In my mind there is a distinct difference between accepting a report and adopting the recommendation of a report. If we accept a report we simply receive it, and say the committee has done the duty entrusted to it. That is an end to it. If we adopt the recommendations of the report, that requires a different motion. My motion was that the Report of the Committee be accepted and placed on file and the Committee be discharged.

Report of Special Committee on the Metric System (continued).

THE PRESIDENT.—I thought that Professor Swain's motion was seconded. Am I correct? Your motion was seconded?

MR. SWAIN.—I believe Mr. Stearns seconded it.

THE PRESIDENT.—The question then would be on the amendment.

MR. CURTIS.—If that covers it, I withdraw my amendment to the original motion. If that is entirely satisfactory to the Society. I do not wish to make any change, but I want to make it definite that we are not in any way required to send out any copies of this report.

THE SECRETARY.—All these remarks will be printed in the *Proceedings,* and I do not think they could send them after that.

THE PRESIDENT.—Then the question as to Professor Swain's motion that the Report of the Committee be accepted and the Committee discharged—are you ready for the question? Those in favor of the motion will signify by saying "aye"; contrary, "no." The motion is carried.

THE SECRETARY.—I have received the following letter:

Letter from St. Louis members.

"ST. LOUIS, MISSOURI, JANUARY 12, 1910.

"AMERICAN SOCIETY OF CIVIL ENGINEERS,
"220 W. 57TH ST.,
"NEW YORK CITY.

"GENTLEMEN:

"The members of the American Society of Civil Engineers, residing in St. Louis and vicinity, while greatly desiring to participate in the Annual Meetings held at the Society House, are as a rule unable to attend them.

"We have, therefore, inaugurated the plan of holding an annual dinner at St. Louis, at the same time as one of the entertainments at Headquarters, thereby enabling us to feel that we are partaking in a slight measure of the benefits and pleasures of the Annual Meeting.

"Our second annual dinner will be given Thursday evening, January 20, 1910.

"Owing to the large attendance at last year's dinner and the general satisfaction expressed, we expect the attendance this year to include practically all local members and such visiting members as may be in St. Louis at the time.

"We desire to send our greetings to the membership present at the Annual Meeting, to express our regrets that we can not all meet with you to assure you of our interest and co-operation in any measures for the benefit of the Society.

"Yours truly,

"O. W. CHILDS,
"Committee for Local Association."

The President.—What shall be done with this letter from the members in St. Louis?

F. W. Hodgdon, M. Am. Soc. C. E.—Mr. President, I move that it be accepted and placed on file.

The President.—I do not think there was any second to the motion.

N. P. Lewis, M. Am. Soc. C. E.—I move that the Secretary be instructed to send congratulations to the St. Louis members and thank them for their letter of appreciation.

Motion duly seconded.

The President.—You have heard the motion. Are you ready for the question? All those in favor will signify by saying "aye"; contrary, "no." Carried unanimously.

The Secretary.—Mr. President, I understand that the tellers will very soon be through with the canvass of the ballot, and in order to fill out the time properly I will say something about the programme.

Announcements regarding Programme.

At the special request of Mr. George Gibbs, of the Pennsylvania Tunnel and Terminal Railroad Company, the members of the Society who wish to inspect the Terminal this afternoon are requested to be on the ground promptly at 2.30. Mr. Gibbs says there is a great deal to see there. They have to walk, I think, some four or five miles anyhow, and he wants to get the parties off promptly, and the hour is 2.30, and the place is the main entrance to the new station, Seventh Avenue and 32d Street.

I think all members who have asked for tickets to the Ashokan Reservoir excursion to-morrow have also received a notice of the change of schedule of the train. The party will leave New York, West 42d Street, at 8.25 in the morning, instead of 8.45, as stated in the programme.

The West Shore Railroad has moved its down-town ferry from Cortlandt Street to Desbrosses Street, and those who want to go via Desbrosses Street will have to leave there at 8.05. The train will leave Weehawken at 8.40, reaching Newburg at 8.58, and Kingston at 10.45.

I think there is no further change, Mr. President, in the programme for the meeting.

Report of Special Committee on Concrete and Reinforced Concrete.

A Member.—There is a report of the Committee on Reinforced Concrete, which came yesterday, and I have not heard it read.

The President.—I beg your pardon, I skipped it.

The Secretary.—I will call for the report of the Committee on Reinforced Concrete.

Mr. Humphrey.—That also was sent to the Secretary.

The President.—We have very few minutes left of the meeting, and please do not make a disturbance in the rear of the hall.

The Secretary read the Report, as follows:

Report of Special Committee on Concrete and Reinforced Concrete (continued).

REPORT OF SPECIAL COMMITTEE ON CONCRETE AND REINFORCED CONCRETE.

To the President and Members of the
American Society of Civil Engineers:

Your Special Committee on Concrete and Reinforced Concrete records with the deepest regret the death of our fellow member, Mr. Julius C. Schaub. Mr. Schaub's experience as a designing engineer in reinforced concrete as well as in structural steel rendered him a particularly desirable member, and one whose loss will be greatly felt.

Your Committee begs to state that the Progress Report which was presented at the last Annual Meeting came up for consideration at the Annual Convention, and was approved by that convention for publication in the *Transactions* of the Society, together with such discussion as might be received from time to time.

Thus far, your Committee has not received any constructive criticism of the Report submitted.

Your Committee is not prepared to present a final report at this time, and asks to be continued.

Respectfully submitted on behalf of the Committee.

C. C. Schneider, *Chairman*,
Richard L. Humphrey, *Secretary*.

The President.—What shall be done with this Report?

It was duly moved and seconded that the Report be accepted and the Committee continued.

The President.—Are you ready for the question? All those in favor of the Report being accepted and the Special Committee on Reinforced Concrete continued signify by saying "aye"; contrary, "no." The motion is carried.

The Secretary.—Mr. President, this Report, you will notice, states that, by the direction of the Annual Convention, this Report shall be published in the *Transactions* of the Society. As a matter of fact, this has not been carried out. I should like to say, in explanation, that the discussions received on that Report were forwarded to the Chairman of that Committee, and he was requested to formulate a reply from the Committee, and at the request of the Chairman of the Committee publication has been withheld. I understand they will now be published.

The President.—I wish to say, gentlemen, that there will be a meeting of the Board of Direction immediately following the adjournment of the meeting of this Society, and it is of the first importance that all new members of the Board of Direction shall attend this meeting for organization—all old members as well—and I hope they will bear this in mind, because the meeting will take only a short time, but it is very important that they should be present.

THE SECRETARY.—I am informed that the tellers will be ready in about five minutes, and I suggest that, in accordance with the custom, a recess be taken until the report comes here. Recess.

It is duly moved and seconded to take a recess.

THE PRESIDENT.—All those in favor of the motion to take a recess for five minutes will say "aye"; contrary, "no." The motion is carried.

After recess:

THE PRESIDENT.—The meeting will come to order to receive the report of the tellers, who have counted the ballots for officers. The Secretary will please read the report. Ballot for Officers.

THE SECRETARY.—The Tellers, Messrs. Horace J. Howe, William J. Carter, and Luzerne S. Cowles, report as follows:

Total number of ballots received			1 280
Defective:	Without signature	22	
	Not entitled to vote	3	
	Void ballot	1	26
Ballots counted			1 254
For President:			
JOHN A. BENSEL			1 222
Scattering			18
For Vice-Presidents:			
JOHN T. FANNING			1 227
HUNTER McDONALD			1 230
Scattering			11
For Treasurer:			
JOSEPH MOSS KNAP			1 237
Scattering			2
For Directors:			
WILLIAM E. BELKNAP			1 200
HORACE LOOMIS			1 194
GEORGE A. KIMBALL			1 191
PERCIVAL ROBERTS, JR.			1 178
CHARLES F. LOWETH			1 193
ARTHUR DEWINT FOOTE			1 181
Scattering			63

THE PRESIDENT.—Gentlemen, I hereby declare the gentlemen whose names are mentioned as the highest in the list formally elected to the offices named. I will appoint Mr. Macdonald and Mr. Stearns to conduct the new President to the platform. You will find him back there. Officers Elected.

Mr. Bensel, it is with great pleasure, sir, that I tender you the symbol of office, the highest office and the greatest honor that the Society can show you.

Remarks by President Bensel.

JOHN A. BENSEL, PRESIDENT, AM. SOC. C. E.—Thank you, Mr Bates. There is one extremely pleasant feature about an election to office by this Society, that is, a man might look over the members and realize that every member, with the exception of very few, and those are not discovered, is his own constituent, and every member can look at the officer elected and realize that pleasant feeling that his own man has been elected, with all that that implies.

I feel fully the honor which has been conferred, and yet will not try to speak much in that vein, for fear of being considered egotistical. I am, however, fully aware of the position of trust and responsibility that belongs to this office, and I hope to be able to so promote certain actions of the Society as to lead it along new lines of activity for the benefit of the profession as a whole, and for the individual membership.

We have come, I think, to a change of condition in regard to the position of the engineer before the public, and it is along those lines that I think the Society should move, with all the resources and powers which it commands, in the future.

Certainly, we have progressed most marvelously in the past few years. The membership has nearly doubled in seven years, with resources in the way of a house and a long purse, and practically untrammelled with any alliances made with other societies, so that we are foot free to operate for the benefit of the profession and for the members individually.

I cannot express more fully the feeling which I have, except that, independent of the fact that the world seems to have moved so fast and under such changing conditions as to make it impossible for a man to state now that he is going to do his duty, but he must be able as a thinking man to look into the complex conditions that confront us, and try in every way to see that the engineer takes that position before the public that his training and his very nature not only entitles him to, but as a matter of patriotism he has got to take in order to guide the world so as to benefit it along the lines of its development.

I thank you.

If there is no further business, a motion to adjourn is in order.

So duly moved and seconded.

THE PRESIDENT.—It is duly moved and seconded that we do now adjourn.

Adjourned.

EXCURSIONS AND ENTERTAINMENTS AT THE FIFTY-SEVENTH ANNUAL MEETING.

Wednesday, January 19th, 1910.—The business meeting adjourned at about 1 P. M. At 2.30 P. M., by invitation of George Gibbs, M. Am. Soc. C. E., Chief Engineer of Electric Traction and Terminal Station Construction of the Pennsylvania Tunnel and Terminal Railroad Company, the members assembled at the main entrance of the new Pennsylvania Railroad Station, Seventh Avenue and Thirty-second Street, where they were received by Mr. Gibbs and representatives of the Company, and conducted in groups through all portions of the Station, the Service Building, the Terminal Yard, etc., and were thus afforded an opportunity to inspect this great work.

At 9 P. M. there was a Reception, with dancing, in the Society House, at which the attendance was about 450.

Thursday, January 20th, 1910.—At the last Annual Meeting there was an all-day Excursion to the Ashokan Reservoir, and it was so interesting and enjoyable that the invitation of the Board of Water Supply for a second visit was accepted gladly. The party left Weehawken at 8.40 A. M. by special train, and the journey to Brown Station was made over the West Shore and Ulster and Delaware Railroads, stops being made at Newburgh and Kingston. Olive Bridge Dam and the dikes of the Ashokan Reservoir were inspected, and also the Contractor's plant, many of those who visited the Reservoir at the last Annual Meeting being thus enabled to note the progress made during the year on the various works.

Lunch was served at the contractor's camp, by invitation of Messrs. MacArthur Bros. Co., and Winston and Co.

The train returning left Olive Bridge Dam at 3 P. M., and the party arrived in New York at 6.30 P. M.

In the evening, at the Society House, Walter McCulloh, M. Am. Soc. C. E., Consulting Engineer, State Water Supply Commission of New York, addressed the Society on "The Conservation of Water Resources in the State of New York," illustrating his remarks with lantern slides. This was followed by a social and informal smoker, at which there was an attendance of about 700.

The following list contains the names of 827 members of various grades, who registered as being in attendance at the Annual Meeting. The list is incomplete, as many members failed to register, and it does not contain the names of any of the guests of the Society or of individual members. The number of guests is estimated at 400.

Ackerman, J. W. . Auburn, N. Y.
Adey, W. H. . . . . . Cohoes, N. Y.
Aiken, W. A. . . . Philadelphia, Pa.
Aikenhead, J. R. . New York City
Alderson, A. B., West Hartford, Conn.
Alexander, H. J. . Brooklyn, N. Y.
Allen, E. Y. . South Orange, N. J.

Allen, H. D...Jersey City, N. J.
Allen, Kenneth..New York City
Alsberg, Julius..New York City
Anderson, W. P..Cincinnati, Ohio
Andrews, Horace..Albany, N. Y.
Archbald, James....Scranton, Pa.
Armstrong, A. F..Albany, N. Y.
Armstrong, R. W..New York City
Asserson, H. R..Brooklyn, N. Y.
Atwood, T. C....Yonkers, N. Y.
Atwood, W. G..Indianapolis, Ind.
Auryansen, F.....Jamaica, N. Y.

Babcock, W. S..New York City
Baird, H. C......New York City
Baker, C. W.....New York City
Baker, Ira O.....Champaign, Ill.
Baker, P. S....Philadelphia, Pa.
Baldridge, J. R..Brooklyn, N. Y.
Baldwin, F. H..Brooklyn, N. Y.
Baldwin, T. W....Boston, Mass.
Ball, L. A..........Newark, N J.
Bamford, W. B....Trenton, N. J.
Bance, C. W..Jersey City, N. J.
Barker, C. W. T.Philadelphia, Pa.
Barker, James M..Elmira, N. Y.
Barnes, M. G.....Albany, N. Y.
Barney, P. C....New York City
Barrett, R. E....New York City
Basinger, J. G....New York City
Bates, Onward......Chicago, Ill.
Becker, E. J....Waterford, N. Y.
Beekman, J. V., Jr..Boston, Mass.
Belden, E. T....Pittsfield, Mass.
Belknap, J. M....New York City
Bellinger, L. F..Philadelphia, Pa.
Belzner, Theodore.New York City
Benton, L. S.....New York City
Bergman, H. M..New York City
Beugler, E. J....New York City
Bieler, A. H.....New York City
Billings, A. W. K..New York City
Bissell, H..........Boston, Mass.
Black, W. M.....New York City
Blackmore, G. G., Long Island City, N. Y.
Blakeley, G. H..So. Bethlehem, Pa.
Blakeslee, Clarence, New Haven, Conn.
Blatt, Max.......New York City
Blood, C. F.....Ridgefield, N. J.
Bogert, C. L....New York City
Boller, A. P....E. Orange, N. J.
Bond, Edward A..Albany, N. Y.
Boucher, W. J....New York City
Bowman, A. L....New York City
Bowman, C. A..Syracuse, N. Y.
Boyd, J. C......New York City
Boyd, R. W......New York City
Boyd, W. C.......Pittsburg, Pa.
Brace, James H..New York City
Brackett, Dexter...Boston, Mass.
Brady, Joseph....New York City
Brendlinger, P. F., Philadelphia, Pa.
Brennan, J. L....New York City
Breuchaud, Jules..New York City
Breuchaud, J. R..New York City
Brewer, Bertram.Waltham, Mass.
Briggs, J. A.....New York City
Briggs, W. C., Long Island City, N. Y.
Broadhurst, W. G., Hackensack, N. J.
Brodie, O. L.....New York City
Brown, A. T......New York City
Brown, LeGrand, San Francisco, Cal.
Brown, Norman F..Pittsburg, Pa.
Brown, Robert H..New York City
Brown, W. P.....New York City
Brush, William W., New York City
Burden, James......Troy, N. Y.
Burdett, F. A....New York City
Burpee, Moses......Houlton, Me.
Burrowes, H. G..New York City
Bush, Edward W.Saybrook, Conn.
Bush, Lincoln.East Orange, N. J.

Caldwell, F. E....Newton, N. J.
Caldwell, G. B...Yonkers, N. Y.

Cantine, E. I. .East Orange, N. J.
Cantwell, H. H. .New York City
Carey, E. G......New York City
Carll, David S. Washington, D. C.
Carmalt, L. J....New York City
Carpenter, C. E...Yonkers, N. Y.
Carr, Albert. .East Orange, N. J.
Carrick, R. E....New York City
Carter, A. E......New York City
Carter, Frank H. Cambridge, Mass.
Carter, W. J.....Cleveland, Ohio
Chadwick, C. R. .New York City
Chapleau, S. J...Ottawa, Canada
Chappell, T. F...New York City
Chase, R. D. .New Bedford, Mass.
Chester, J. N......Pittsburg, Pa.
Christian, G. L. .New York City
Christie, W. W. .Paterson, N. J.
Christy, G. L....New York City
Church, E. C....New York City
Church, F. B....New York City
Churchill, C. S.....Roanoke, Va.
Clark, W. G......Tenafly, N. J.
Clarke, E. W. .Pleasantville, N. Y.
Clarke, G. C.....New York City
Cleveland, L. B. Watertown, N. Y.
Codwise, E. B....Kingston, N. Y.
Codwise, H. R....New York City
Coffin, Amory. South Orange, N. J.
Coffin, T. DeL....Katonah, N. Y.
Cole, H. J.....Morristown, N. J.
Collier, B. C....New York City
Conger, A. A....New York City
Conard, C. K....New York City
Connell, H. L. Brown Station, N.Y.
Cook, F. S........Yonkers, N. Y.
Cook, J. W........Passaic, N. J.
Coombs, R. D....New York City
Coomer, R. M.....Buffalo, N. Y.
Cooper, David R. .Albany, N. Y.
Cornell, J. N. H. .New York City
Corthell, A. B., Hastings-on-Hudson, N. Y.
Coulter, W. S.....Albany, N. Y.
Covert, C. C.......Albany, N. Y.
Cowles, L. S.......Boston, Mass.

Crane, A. S......New York City
Crane, C. A......New York City
Crehore, W. W...New York City
Cresson, B. F., Jr. .New York City
Crooks, C. H....New York City
Crosby, Hewitt....New York City
Crosby, W. W....Baltimore, Md.
Crowell, Foster...New York City
Cuddeback, A. W. .Paterson, N. J.
Cummings, Noah. .New York City
Cummings, R. A. .Pittsburg, Pa.
Currier, C. G....New York City

Dailey, J. A. .East Orange, N. J.
Dakin, A. H., Jr. .New York City
Dalrymple, F. W. .Bayonne, N. J.
Darling, J. H.....Duluth, Minn.
Darrow, W. J....New York City
Davis, C. B......New York City
Davis, C. E. Brown Station, N. Y.
Davis, J. L......New York City
Davis, W. R......Albany, N. Y.
Dean, Arthur W...Boston, Mass.
Dean, Luther.....Taunton, Mass.
DeBerard, W. W. .New York City
Derby, C. C. .Richmond Hill, N. Y.
Devin, George...New York City
Develin, R. G...Philadelphia, Pa.
Devlin, H. S.....Brooklyn, N. Y.
Deyo, S. L. F....New York City
Diamant, A. H....New York City
Dimon, D. Y......Passaic, N. J.
Dorrance, W. T....Albany, N. Y.
Downes, A. K....Kenbridge, Va.
Dunham, H. F...New York City

Earle, Thomas......Steelton, Pa.
Easterbrook, F. J. .New York City
Eckersley, J. O...New York City
Edwards, D. G....Walden, N. Y.
Edwards, H. W. .New York City
Edwards, J. H....Passaic, N. J.
Ehrbar, L. H....New York City
Elliott, C. G. .Washington, D. C.
Elliott, J. W.....Burlington, Vt.
Ellis, J. W.....Woonsocket, R. I.

Ely, J. A........New York City
Emerson, G. C.,
Jamaica Plain, Mass.
Endicott, M. T. Washington, D. C.
Ensign, G. W....Harrisburg, Pa.
Esselstyn, H. H....Detroit, Mich.
Estabrook, G. M..New York City
Ewing, W. W....Westfield, N. J.

Fairchild, S. E., Jr.,
Philadelphia, Pa.
Falk, M. S.......New York City
Fanning, J. T. Minneapolis, Minn.
Farley, J. M..White Plains, N. Y.
Farley, P. P....Brooklyn, N. Y.
Faucette, W. D..Portsmouth, Va.
Fay, F. H.........Boston, Mass.
Federlein, W. G..New York City
Felgenhauer, F. J. Brooklyn, N. Y.
Fenn, W. H....Wilmington, Del.
Fenton, L. G....New York City
Fetherston, J. T..New York City
Fiebeger, G. J..West Point, N. Y.
Firth, E. W......Jamaica, N. Y.
Fischer, T. C....Elizabeth, N. J.
Fisher, E. A....Rochester, N. Y.
Fisher, Wager...Bryn Mawr, Pa.
Fitch, C. L......Brooklyn, N. Y.
FitzGerald, D...Brookline, Mass.
Fletcher, Robert..Hanover, N. H.
Flinn, A. D......Yonkers, N. Y.
Ford, H. C......New York City
Ford, W. G......Brooklyn, N. Y.
Forrest, C. N......Maurer, N. J.
Fort, E. J.......Brooklyn, N. Y.
Foss, F. E.......Yonkers, N. Y.
Fougner, Hermann,
New York City
Francis, G. B....New York City
Fraser, C. E. Richmond Hill, N.Y.
Frazer, J. S.....Brooklyn, N. Y.
Freeman, M. H...New York City
French, A. H....Brookline, Mass.
French, C. R....Brooklyn, N. Y.
French, J. B....New York City
Frink, E. A.....Portsmouth, Va.
Frisell, E. H......New York City
Fuertes, J. H....New York City
Fuller, F. L.......Boston, Mass.
Fuller, G. W.....New York City
Fuller, W. B.....New York City
Furber, W. C..Philadelphia, Pa.

Gahagan, W. H..Brooklyn, N. Y.
Galvin, J. A. Mechanicsville, N. Y.
Gandolfo, J. H...New York City
Gardiner, F. W..Yonkers, N. Y.
Garrison, F. L..Philadelphia, Pa.
Gaston, L. P....Somerville, N. J.
Giddings, F......Atchison, Kans.
Gifford, G. E....New York City
Gillen, W. J.,
Brown Station, N. Y.
Gilman, Charles..Plainfield, N. J.
Gladding, H. H.,
New Haven, Conn.
Goldsborough, J. B.,
New York City
Goodman, Joseph..New York City
Goodman, Louis..New York City
Goodrich, E. P...New York City
Goodsell, D. B....New York City
Gould, C. M..Cold Spring, N. Y.
Gould, W. T....Hastings, N. Y.
Gow, C. R..West Roxbury, Mass.
Grady, C. B..West Orange, N. J.
Graham, C. H....New York City
Granbery, J. H..New York City
Gray, J. H........Orange, N. J.
Green, B. R....Washington, D. C.
Green, C. N.....New York City
Green, F. M......New York City
Greene, Carlton,
South Orange, N. J.
Greene, G. S., Jr..New York City
Greene, W. S. New Brunswick, N.J.
Greenlaw, R. W. Cold Spring, N.Y.
Gregory, C. E...Mt. Kisco, N. Y.
Gregory, J. H.....Newark, N. J.
Greiner, J. E.....Baltimore, Md.

Griffin, W. R. W.,
Rochester, N. Y.
Grimes, E. L........Troy, N. Y.
Grimm, C. R....Brooklyn, N. Y.
Gross, C. A.......New York City
Guise, Philip.....Brooklyn, N. Y.
Guthrie, E. B.....Buffalo, N. Y.

Hackney, J. W.Atlantic City, N. J.
Hague, C. A.....New York City
Haight, S. S......New York City
Haines, C. W..Philadelphia, Pa.
Haines, E. G....Brooklyn, N. Y.
Haldeman, W. S.Philadelphia, Pa.
Hale, H. M....High Falls, N. Y.
Hale, R. A......Lawrence, Mass.
Hale, R. K........Boston, Mass.
Hall, M. W......New York City
Hall, W. M..Parkersburg, W. Va.
Hallihan, J. P....New York City
Hallock, J. C......Newark, N. J.
Hamilton, J. W..New York City
Hammond, G. T..Brooklyn, N. Y.
Hanavan, W. L.Newburgh, N. Y.
Hancock, R. R....New York City
Harby, Isaac......Trenton, N. J.
Hardaway, B. H...Columbus, Ga.
Harrington, F. F....Norfolk, Va.
Harte, C. R..New Haven, Conn.
Hartman, A. F....Baltimore, Md.
Harwood, G. A...New York City
Hasbrouck, Oscar...Cohoes, N. Y.
Haskins, W. J....New York City
Haslam, E. E......Albany, N. Y.
Hauck, William..Brewster, N. Y.
Hawkins, Irving,
South Orange, N. J.
Hayes, H. W.......Boston, Mass.
Hayes, S. W......Geneva, N. Y.
Haynes, C. S....Brooklyn, N. Y.
Hazelton, C. W.,
Turners Falls, Mass.
Hazen, Allen.....New York City
Hazen, J. V......Hanover, N. H.
Healy, J. R.......New York City

Heller, J. W......Newark, N. J.
Henderson, J. T..Hartford, Conn.
Hering, Rudolph..Montclair, N. J.
Herrick, J. J....New York City
Hewes, V. H....New York City
Hewitt, George...New York City
Higgins, C. H..Jersey City, N. J.
Higgins, H. K..Dorchester, Mass.
Higgins, J. W..Roselle Park, N.J.
Higginson, J. Y.,
New Rochelle, N. Y.
Hilton, H. L....Newburgh, N. Y.
Hitchcock, F. C..New York City
Hobby, A. S....Philadelphia, Pa.
Hodgdon, B. A...New York City
Hodgdon, F. W....Boston, Mass.
Hodge, H. W....New York City
Hoff, Olaf........New York City
Hogan, J. P..High Falls, N. Y.
Holbrook, Percy..New York City
Holden, E. H....New York City
Holgate, Henry,
Montreal, Que., Canada
Holtzman, S. F..New York City
Honness, G. G.,
Pleasantville, N. Y.
Hood, J. N....Newburgh, N. Y.
Horne, H. W....Cornwall, N. Y.
Hotchkiss, L. J.....Chicago, Ill.
Hovey, O. E.....Plainfield, N. J.
Howe, C. E.....Hastings, N. Y.
Howe, E. W........Boston, Mass.
Howe, G. E........Boston, Mass.
Howe, H. J......Yonkers, N. Y.
Howell, W. A......Newark, N. J.
Hoyt, J. C....Washington, D. C.
Hoyt, W. E.....Rochester, N. Y.
Hubbell, G. S...Flushing, N. Y.
Hudson, C. W....New York City
Hudson, H. W..Woodside, N. Y.
Humphrey, R. L.Philadelphia, Pa.
Hunt, C. A......New York City
Hunt, C. E......New York City
Hunt, C. W.....New York City
Hunt, L. A..........Iola, Kans.

Hurlbut, H. B....Newark, N. J.
Hyatt, Caleb.....New York City

Ilsley, A. B....Washington, D. C.
Immediato, G....Montclair, N. J.
Ives, A. S....Poughkeepsie, N. Y.

Jacoby, H. S........Ithaca, N. Y.
Janes, G. P.......Roselle, N. J.
Janvrin, N. H..Newburgh, N. Y.
Jewel, L. L..Edgewood Park, Pa.
Johnson, A......New York City
Johnson, G. A....New York City
Johnson, Rankin,
Port Washington, N. Y.
Johnson, T. H.....Pittsburg, Pa.
Johnston, C. T...Cheyenne, Wyo.
Jones, Pusey.....New York City
Jones, S. R......New York City
Jordan, E. C......Portland, Me.

Karner, W. J....New York City
Kastl, A. E......Peekskill, N. Y.
Kaufman, Gustave.New York City
Keays, R. H....New Paltz, N. Y.
Keefer, C. H.Ottawa, Ont., Canada
Keith, H. C......New York City
Keller, O. B.....New York City
Kelley, W. D.....Yonkers, N. Y.
Kiehm, Charles....Albany, N. Y.
Kimball, G. A.....Boston, Mass.
Kimball, W. H..Davenport, Iowa
King, Wallace, Jr.New York City
Kinnear, W. S.....Detroit, Mich.
Kinney, W. M....Pittsburg, Pa.
Kirchner, P. A...New York City
Kirkwood, H. C...New York City
Kittredge, G. W...Yonkers, N. Y.
Knap, J. M......Catskill, N. Y.
Knickerbocker, C. E.,
Middletown, N. Y.
Knight, F. B........Chicago, Ill.
Knighton, J. A....New York City
Knowles, Morris...Pittsburg, Pa.
Knox, S. B......New York City
Kornfeld, A. E...New York City
Kreiner, H. P....Newark, N. J.
Kuichling, E.....New York City

LaChicotte, H. A..New York City
Lamb, Richard....New York City
Lambie, C. S......Pittsburg, Pa.
Langthorn, J. S..Kingston, N. Y.
Langton, John....New York City
Lannan, L. E....Wilkinsburg, Pa.
Lane, H. A.......Baltimore, Md.
Lavis, F......Mt. Vernon, N. Y.
Larsson, C. G. E..New York City
Leather, B. H....New York City
Leavitt, C. W., Jr.New York City
Lee, E. M........New York City
Lee, J. L......Mt. Vernon, N. Y.
Lee, W. B........Hillburn, N. Y.
Lentilhon, Eugene,
Bay Shore, N. Y.
Lesley, R. W...Philadelphia, Pa.
Lewis, E. W..New Haven, Conn.
Lewis, N. P......New York City
Lex, W. I......Philadelphia, Pa.
Lindau, A. E......St. Louis, Mo.
Lindenthal, Gustav,
New York City
Llewellyn, F. T..New York City
Lobo, Carlos.....Brooklyn, N. Y.
Lochridge, E. E.Springfield, Mass.
Loewenstein, Jacob,
New York City
Logan, W. S....Arlington, N. J.
Long, E. McL....New York City
Look, M. J..Brown Station, N. Y.
Loomis, Horace.Mt. Vernon, N. Y.
Low, G. E.......New York City
Loweth, C. F.......Chicago, Ill.
Lowinson, O......New York City
Lowry, John, Jr..New York City
Lucas, G. L......New York City
Lucius, Albert....New York City
Ludwig, J. A....New York City
Lundie, John....New York City
Luster, W. H., Jr.Elizabeth, N. J.

Lyford, O. S., Jr. .New York City
Lyle, W. T..........Easton, Pa.

Macdonald, C....New York City
MacGregor, R. A. .New York City
Machen, H. B....New York City
McClave, S. W., Jr., Cliffside Park, N. J.
McCulloh, Walter. .Albany, N. Y.
McCurdy, H. S. R., Brown Station, N. Y.
McDonald, Hunter, Nashville, Tenn.
McFetridge, W. S. Greenville, Pa.
McKenzie, T. H., Southington, Conn.
McLure, N. R...Phœnixville, Pa.
McMinn, T. J...Brooklyn, N. Y.
McNab, William, Montreal, Que., Canada
McNeal, John.......Easton, Pa.
Mair, J. W....Mt. Vernon, N. Y.
Maltby, F. B....Philadelphia, Pa.
Manley, Henry.....Boston, Mass.
Manley, L. B. West Roxbury, Mass.
Marden, H. H., Jr..New York City
Marple, W. M......Scranton, Pa.
Marshall, C. E. D., Garden City, N. Y.
Marshall, R. A...New York City
Mason, Francis...Plainfield, N. J.
Matheson, E. G...New York City
Matheson, J. D., Winnipeg, Man., Canada
Matlaw, I. S. .Amsterdam, N. Y.
Maurice, G. H...Harrisburg, Pa.
Mead, C. A. Upper Montclair, N. J.
Meadowcroft, W. .New York City
Meem, J. C......Brooklyn, N. Y.
Mehren, E. J....New York City
Melius, L. L......New York City
Mercer, C. H........Steelton, Pa.
Merrill, Ogden....New York City
Merriman, Thaddeus, Essex Fells, N. J.
Merryman, W. C. .New York City
Metcalf, Leonard. .Boston, Mass.
Miller, H. A., Newton Highlands, Mass.
Miller, Max M....Yonkers, N. Y.
Miller, R. P......New York City
Mills, C. M....Philadelphia, Pa.
Modjeski, Ralph.....Chicago, Ill.
Mogensen, O. E. .New York City
Moisseiff, L. S....New York City
Molitor, D. A......Ithaca, N. Y.
Molitor, Frederic. .New York City
Montfort, R......Louisville, Ky.
Moore, E. J......Yonkers, N. Y.
Moore, F. F....Hawthorne, N. Y.
Moore, L. E...Newtonville, Mass.
Moore, W. H. .New Haven, Conn.
Mordecai, A.....Cleveland, Ohio
Morrison, C. E....New York City
Morrison, H. J....Walden, N. Y.
Morse, G. F......Bayonne, N. J.
Mott, W. E........Pittsburg, Pa.
Mueser, W.......New York City
Musson, E. F.....Norwich, N. Y.
Murphy, J. J....Yonkers, N. Y.
Myers, C. H......New York City
Myers, J. H. .White Plains, N. Y.

Neale, J. C........Pittsburg, Pa.
Nelson, F. B. .East Orange, N. J.
Nelson, William, Binghamton, N. Y.
Newman, A. T...New York City
Nichol, H. S....New York City
Nichols, A. R....Brooklyn, N. Y.
Nichols, C. H. .New Haven, Conn.
Noble, Alfred....New York City
Norris, W. H......Portland, Me.
Norton, A. G....Otisville, N. Y.
North, E. P......New York City
Northrop, A. A., Brown Station, N. Y.
Noyes, H. L......New York City
Nunn, P. N.........Provo, Utah
Nye, A. S........New York City

Obreiter, J. W....Hoboken, N. J.
O'Brien, D. B...Syracuse, N. Y.
O'Brien, J. H....New York City
Odell, F. S...Port Chester, N. Y.
Ogden, H. N.......Ithaca, N. Y.
Olmsted, A. E....New York City
Opdyke, Stacy B., Jr., New York City
O'Rourke, J. F...New York City
Orr, Alexander, Gloversville, N. Y.
Orrok, G. A.....Brooklyn, N. Y.
Osborn, F. C....Cleveland, Ohio
Osborn, K. H....Rochester, N. Y.
Osgood, J. O....Plainfield, N. J.
Ostrup, J. C......New York City
Ott, S. J.....East Orange, N. J.
Owen, James....Montclair, N. J.
Owen, K. D.....Montclair, N. J.
Oxholm, T. S., West New Brighton, N. Y.

Parker, C. J......New York City
Parker, J. L......New York City
Parmley, W. C., Upper Montclair, N. J.
Parsons, G. W......Steelton, Pa.
Parsons, H. A..Stamford, Conn.
Parsons, R. S....Hornell, N. Y.
Patterson, R. Y., Springfield, Mass.
Payne, E. V. R., Fort Edward, N. Y.
Peabody, W. W., White Plains, N. Y.
Pegram, G. H...New York City
Pemoff, J. J......New York City
Pendlebury, Edward, Arlington, N. J.
Perkins, A. H......Albany, N. Y.
Perkins, P. S...Providence, R. I.
Perrine, George..New York City
Peterson, John...New York City
Pfau, J. W......New York City
Pflueger, A. C....New York City
Philips, J. H......Newark, N. J.
Plogsted, W. J....New York City
Pohl, C. A.......New York City
Polk, A......Pauls Valley, Okla.
Pollock, C. D....New York City
Pond, H. B.. ..New York City
Pond, H. O........Tenafly, N. J.
Porter, H. T......Greenville, Pa.
Potts, Clyde.....New York City
Powers, C. V. V..New York City
Powers, J. A........Troy, N. Y.
Pratt, Arthur H..New York City
Preston, C. H....Norwich, Conn.
Preston, C. H., Jr., Waterbury, Conn.
Preston, H. W....Elmira, N. Y.
Price, P. L...East Orange, N. J.
Priest, B. B......New York City
Prince, A. D.....New York City

Quimby, C. H., Jr., Mt. Vernon, N. Y.
Quimby, H. H..Philadelphia, Pa.
Quincy, C. F....New York City

Ray, G. J....East Orange, N. J.
Read, R. L........Malden, Mass.
Reed, C. S.......New York City
Reed, W. B......New York City
Regester, H. S., Jr., Baltimore, Md.
Reid, H. A......New York City
Reimer, A. A..East Orange, N. J.
Reimer, F. A..East Orange, N. J.
Reynolds, A. M....Newark, N. J.
Rice, G. S.......New York City
Rice, R. G......Stamford, Conn.
Richardson, Clifford, New York City
Richardson, J. D..Corona, N. Y.
Richardson, J. H..New York City
Richardson, R. D...Scranton, Pa.
Richardson, T. F.Brooklyn, N. Y.
Richmond, J. P. W., New York City

Ridgway, R. Poughkeepsie, N. Y.
Riedel, J. C.....Brooklyn, N. Y.
Riegner, W. B..Philadelphia, Pa.
Riggs, M. J........Toledo, Ohio
Rights, L. D.....New York City
Ripley, J. W.....New York City
Ripley, Joseph.....Albany, N. Y.
Ripley, T. M......Fulton, N. Y.
Robbins, F. H....New York City
Roberts, H. W...New York City
Robinson, E. F...New York City
Robinson, E. W..New York City
Rockwood, E. F., Newton Center, Mass.
Rogers, H. L....New York City
Rohrer, Grant....New York City
Rohrer, J. B......Lancaster, Pa.
Rollins, J. W., Jr..Boston, Mass.
Ropes, Horace...Brookline, Mass.
Rose, R. V..Niagara Falls, N. Y.
Rosenberg, F....Montclair, N. J.
Rowland, C. B...Brooklyn, N. Y.
Ruddle, John..Mauch Chunk, Pa.
Rust, C. H. Toronto, Ont., Canada
Ruttan, H. N., Winnipeg, Man., Canada
Ryan, M. H......New York City
Ryder, E. M. T...New York City

Sanborn, F. B..Cambridge, Mass.
Sanborn, J. F....Peekskill, N. Y.
Sanford, H. C....New York City
Sauer, A. F......Elizabeth, N. J.
Savage, S. M......Albany, N. Y.
Sayers, E. L.....New York City
Sayles, R. W....New York City
Scammell, J. K., St. John, N. B., Canada
Schaeffer, Amos..New York City
Schall, F. E., South Bethlehem, Pa.
Schermerhorn, R., Jr., New York City
Schmid, F. R.....Bethlehem, Pa.
Schmitz, F. C....New York City
Schneeweiss, A. E., Paterson, N. J.
Schneider, C. C., Philadelphia, Pa.
Schulze, H. A., East Oakland, Cal.
Schwitzer, J. E., Winnipeg, Man., Canada
Seabury, G. T....New York City
Searle, C. D.....New York City
Searle, L. F., Brown Station, N. Y.
Sears, W. H....Plymouth, Mass.
Selby, O. E.....Cincinnati, Ohio
Senior, F. S..Montgomery, N. Y.
Serber, D. C......New York City
Shailer, R. A......Boston, Mass.
Shedd, G. G.....New York City
Shellenberger, L. R., Bayonne, N. J.
Sherman, A. L., White Plains, N. Y.
Sherrerd, J. M.......Easton, Pa.
Sherrerd, M. R....Newark, N. J.
Shertzer, T. B....Baltimore, Md.
Simpson, G. F....New York City
Sitt, W. T.......New York City
Skillin, E. S...Glen Ridge, N. J.
Skinner, F. W., Tompkinsville, N. Y.
Skinner, J. F...Rochester, N. Y.
Sloan, W. G......New York City
Slocum, C. L......Newark, N. J.
Small, J. H., Jr..New York City
Smith, A. O. Port Jefferson, N. Y.
Smith, Augustus..New York City
Smith, F. B....Mare Island, Cal.
Smith, H. E.....Syracuse, N. Y.
Smith, H. S....Wilkes-Barre, Pa.
Smith, J. Waldo..New York City
Smith, Joseph....New York City
Smith, M. H..White Plains, N. Y.
Smith, W. F.....New York City
Smith, W. M., Sr., West New Brighton, N. Y.

Smith, W. T.....New York City
Snow, C. H......New York City
Snow, F. H......Harrisburg, Pa.
Snow, J. B. Richmond Hill, N. Y.
Snow, J. P........Boston, Mass.
Sonne, Otto......New York City
Soper, G. A......New York City
Souder, Harrison...Cornwall, Pa.
Souther, T. W..Newburgh, N. Y.
Spaulding, C. L..Yonkers, N. Y.
Spear, W. E....Brooklyn, N. Y.
Spencer, H......New York City
Spilsbury, E. G.,
New Rochelle, N. Y.
Splitstone, C. H.,
East Orange, N. J.
Sprague, E. L., Jr..Valhalla, N. Y.
Sprague, N. S....Pittsburg, Pa.
Sproul, A. A.....Peekskill, N. Y.
Stanton, F. McM. New York City
Starr, H. H....Philadelphia, Pa.
Stearns, F. L....Scarsdale, N. Y.
Stearns, F. P......Boston, Mass.
Stearns, R. H....New York City
Steere, A. E..Fort Hunter, N. Y.
Stern, E. W......New York City
Stevens, E. W..Hackensack, N. J.
Stevens, G. M...Winthrop, Mass.
Stevens, H. E....St. Paul, Minn.
Stewart, J. M....New York City
Stickney, G. F.....Albany, N. Y.
Stoddard, G. C....New York City
Stoddard, R. F....Milford, Conn.
Stone, W. W......Walden, N. Y.
Storey, W. B., Jr....Chicago, Ill.
Stowitts, G. P...New York City
Strachan, Joseph. Brooklyn, N. Y.
Strachan, R. C.,
Richmond Hill, N. Y.
Strobel, C. L.......Chicago, Ill.
Strong, Mason R. New York City
Stuart, Francis L. New York City
Sumner, Horace A..Denver, Colo.
Suter, Russell....New York City
Sutton, Frank. Washington, D. C.
Swain, G. F.......Boston, Mass.
Swensson, Otto J..Pittsburg, Pa.
Swindells, J. S..Brooklyn, N. Y.
Sykes, George....New York City

Taber, George A. Brooklyn, N. Y.
Taggart, Ralph C. New York City
Talbot, A. N........Urbana, Ill.
Talbot, Earle,
San Francisco, Cal.
Talbot, F. M..Glen Ridge, N. J.
Tallman, Leroy. Portsmouth, R. I.
Tarr, Charles W..Brooklyn, N. Y.
Taylor, Charles F. New York City
Taylor, Lucian A..Boston, Mass.
Taylor, W. G....Montclair, N. J.
Tenney, Willis R. Brooklyn, N. Y.
Terrell, W. H..Wilmington, Del.
Terry, A. H..New Haven, Conn.
Terry, J. H.....Philadelphia, Pa.
Thacher, Edwin..New York City
Thoma, Jacob,
Long Island City, N. Y.
Thomas, C. D...Brooklyn, N. Y.
Thomes, Edwin H. Jamaica, N. Y.
Thompson, S. C..New York City
Thompson, Sanford E.,
Newton Highlands, Mass.
Thomson, Alex., Jr.,
Walden, N. Y.
Thomson, S. F..New Paltz, N. Y.
Thomson, T. K...New York City
Thornley, Julian..Albany, N. Y.
Tidd, A. W..White Plains, N. Y.
Tighe, James L...Holyoke, Mass.
Tillson, G. W...Brooklyn, N. Y.
Tilt, Garret E....New York City
Tinkham, S. E....Boston, Mass.
Tirrell, C. E...Mt. Vernon, N. Y.
Tompkins, E. DeV.,
Pelham, N. Y.
Tompson, G. M..Wakefield, Mass.
Tooker, F. W....New York City
Torrance, W. M.,
East Orange, N. J.

Torrey, J. E......Paterson, N. J.
Tozzer, A. C......New York City
Trautwine, J. C., Jr., Philadelphia, Pa.
Travell, W. B...Plainfield, N. J.
Tribus, Louis L..New York City
Triest, W. G.....New York City
Trotter, A. W....New York City
Trout, Charles E..New York City
Trow, F. H.Brown Station, N. Y.
Tucker, Lester W.New York City
Tucker, W. C...Englewood, N. J.
Tull, Richard W..New York City
Turner, E. K......Boston, Mass.
Tuttle, Arthur S..New York City

Ulrich, Daniel....Katonah, N. Y.
Underwood, H. W., Philadelphia, Pa.

Vandervoort, B. F.New York City
Van Horne, J. G..New York City
Van Keuren, C. A., Jersey City, N. J.
Van Norden, E. M., Brooklyn, N. Y.
Van Vleck, J. B..Brooklyn, N. Y.
Van Winkle, Edward, Brooklyn, N. Y.
Verrill, G. E..New Haven, Conn.
Vier, H.....White Plains, N. Y.
Vinton, T. M....New York City
Vogel, John L..Jersey City, N. J.
Volck, A. G...Mt. Vernon, N. Y.
Voorhees, Paul...Harrisburg, Pa.
Vredenburgh, W., Jr., Woodmere, N. Y.

Wachter, C. L...New York City
Waddell, M......New York City
Wagner, Harry E.Andover, N. J.
Wagner, J. C...Philadelphia, Pa.
Waite, Guy B....New York City
Waldron, S. P...New York City
Walker, E. L....Stapleton, N. Y.
Walker, Frank H...Franklin, Pa.
Walker, J. W.....Pittsburg, Pa.
Walton, Harry C.New York City
Ward, C. D......New York City
Ward, Edward A..Newark, N. J.
Wardle, E. B....New York City
Warren, H. A....New York City
Washington, W. DeH., New York City
Wason, L. C......Boston, Mass.
Wasser, T. J..Jersey City, N. J.
Watkins, F. W., White Plains, N. Y.
Watson, G. L.Atlantic City, N. J.
Webster, G. S...Philadelphia, Pa.
Webster, W. R..Philadelphia, Pa.
Wegmann, E....New York City
Wells, C. E..White Plains, N. Y.
Wells, Joseph A..New York City
Wendt, Edwin F..Pittsburg, Pa.
Wentworth, G. L.New York City
Weston, F. S...Middleboro, Mass.
Wheeler, D. M., Springfield, Mass.
Whipple, G. C....New York City
White, T. S....Beaver Falls, Pa.
White, W. M....New York City
Whitney, F. O.....Boston, Mass.
Whitney, T. B., Jr., New York City
Whittemore, W. F.Hoboken, N. J.
Wiggin, E. W.New Haven, Conn.
Wiggin, T. H....Scarsdale, N. Y.
Wilcock, Frederick, Brooklyn, N. Y.
Wildes, Waldo G...Rome, N. Y.
Wiley, W. H.....New York City
Wilkes, J. K., New Rochelle, N. Y.
Wilkins, G. S....New York City
Willard, N. R., North Cambridge, Mass.
Wilson, C. A...Cincinnati, Ohio
Wilson, C. W. S., New Rochelle, N. Y.

Wilson, E. B.......Chicago, Ill.
Wilson, H. M. Washington, D. C.
Wilson, P. H...Philadelphia, Pa.
Wilson, T. L....Brooklyn, N. Y.
Wilson, W. T...New York City
Wilson, W. W...Brooklyn, N. Y.
Winsor, F. E. White Plains, N. Y.
Witmer, F. P..East Orange, N. J.
Wölfel, Paul L....Pittsburg, Pa.
Wolverton, I. M., Mt. Vernon, Ohio
Wood, Henry B...Boston, Mass.
Woodard, S. H...Scarsdale, N. Y.
Woods, H. D. West Newton, Mass.
Woodworth, R. B..Pittsburg, Pa.
Woolley, A. F., Sylvan Beach, N. Y.
Wortendyke, N. D., Jersey City, N. J.
Worthington, Charles, New York City
Wrenn, J. F......Newark, N. J.
Wyckoff, C. R., Jr., Brooklyn, N. Y.
Wyman, A. M. East Orange, N. J.

Yates, P. K., Tomkins Cove, N. Y.
Yereance, W. B..New York City
Young, C. G......New York City

Zabriskie, A. M..Plainfield, N. J.

ANNOUNCEMENTS

The House of the Society is open from 9 A. M. to 10 P. M., every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

MEETINGS.

March 2d, 1910.—8.30 P. M.—A paper entitled "The Improved Water and Sewage Works of Columbus, Ohio," by John H. Gregory, M. Am. Soc. C. E., will be presented for discussion.

This paper was printed in *Proceedings* for January, 1910.

March 16th, 1910.—8.30 P. M.—At this meeting two papers will be presented for discussion, as follows: "A Concrete Water Tower, by A. Kempkey, Jun. Am. Soc. C. E.; and "Some Mooted Questions in Reinforced Concrete Design," by Edward Godfrey, M. Am. Soc. C. E.

These papers are printed in this number of *Proceedings*.

April 6th, 1910.—8.30 P. M.—Two papers will be presented for discussion, as follows: "The New York Tunnel Extension of the Pennsylvania Railroad: The Terminal Station-West," by B. F. Cresson, Jr., M. Am. Soc. C. E.; and "The New York Tunnel Extension of the Pennsylvania Railroad: The Bergen Hill Tunnels," by F. Lavis, M. Am. Soc. C. E.

These papers are printed in this number of *Proceedings*.

April 20th, 1910.—8.30 P. M.—At this meeting a paper by Herbert M. Wilson, M. Am. Soc. C. E., entitled, "Federal Investigations of Mine Accidents, Structural Materials, and Fuels at the United States Testing Station, Pittsburg, Pa."

This paper is printed in this number of *Proceedings*.

SUBSCRIPTION PRICE TO THE PUBLICATIONS OF THE SOCIETY

The following subscription rates have been fixed by the Board of Direction for the publications of the Society:

Proceedings, ten Numbers per annum, $8. Price for single numbers, $1.

Transactions, four Volumes per annum, $12. Price for single volumes, $4.

On the above prices there is a discount of 25% to members who desire extra copies of any of these publications, to Libraries, and to Book-dealers.

There is also an additional charge per annum, to cover foreign postage, of 75 cents for *Proceedings* and $1 for *Transactions*, or 8 cents and 25 cents, respectively, for single numbers.

A special subscription rate has been fixed by the Board for the *Proceedings* of the Society for the benefit of Students in Technical Schools. This rate is $4.50 per annum, and is available to any *bona fide* student of any technical school.

MEETINGS OF THE SAN FRANCISCO ASSOCIATION OF MEMBERS, AM. SOC. C. E.

The San Francisco Association of Members of the American Society of Civil Engineers holds regular bi-monthly meetings, with banquet, and weekly informal luncheons. The former are held at 6 P. M., at the Palace Hotel, on the third Friday of February, April, June, August, October, and December, the latter being the Annual Meeting of the Association.

Informal luncheons are held at 12.15 P. M. every Wednesday, and the place of meeting may be ascertained by communicating with the Secretary of the Association, E. T. Thurston, Jr., Assoc. M. Am. Soc. C. E., 623 Wells Fargo Building.

The by-laws of the Association provide for the extension of hospitality to any members of the Society who may be temporarily in San Francisco, and any such member will be gladly welcomed as a guest of the Association at any of the above meetings, if he will notify the Secretary that he is in San Francisco.

PAPERS AND DISCUSSIONS

It is hoped that members and others who take part in the discussion of the papers presented will revise their remarks promptly, and that all written communications from those who cannot attend the meetings will be sent in at the earliest possible date after the issue of a paper in *Proceedings*. The quarterly issue of volumes of *Transactions* is dependent on the closing of discussions, and the co-operation of the membership is now more necessary in this matter than heretofore, because a definite date of issue for each volume must be maintained.

All papers accepted by the Publication Committee are classified by the Committee with respect to their availability for discussion at meetings.

Papers, which, from their general nature, appear to be of a character suitable for oral discussion, will be published as heretofore in *Proceedings,* and set down for presentation to a future meeting of the Society, and, on these, oral discussion, as well as written communications, will be solicited.

All papers which do not come under this heading, that is to say, those which, from their mathematical or technical nature, in the opinion of the Committee, are not adapted to oral discussion, will not be scheduled for presentation to any meeting. Such papers will be published in *Proceedings* in the same manner as those which are to be presented at meetings, but written discussions, only, will be requested for subsequent publication in *Proceedings* and with the paper in the volumes of *Transactions*.

PRIVILEGES OF ENGINEERING SOCIETIES EXTENDED TO MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Members of the American Society of Civil Engineers will be welcomed by the following Engineering Societies, both to the use of their Reading Rooms and at all Meetings:

American Institute of Mining Engineers, 29 West Thirty-ninth Street, New York City.

Associação dos Engenheiros Civis Portuguezes, Lisbon, Portugal.

Australasian Institute of Mining Engineers, Melbourne, Victoria, Australia.

Boston Society of Civil Engineers, 715 Tremont Temple, Boston, Mass.

Brooklyn Engineers' Club, 117 Remsen Street, Brooklyn, N. Y.

Canadian Society of Civil Engineers, 413 Dorchester Street, West, Montreal, Que., Canada.

Civil Engineers' Society of St. Paul, St. Paul, Minn.

Cleveland Engineering Society, 718 Caxton Building, Cleveland, Ohio.

Cleveland Institute of Engineers, Middlesbrough, England.

Colorado Association of Members, Am. Soc. C. E., H. J. Burt, Secy., 235 Equitable Building, Denver, Colo.

Engineers' and Architects' Club of Louisville, Ky., 303 Norton Building, Fourth and Jefferson Streets, Louisville, Ky.

Engineers' Club of Baltimore, Baltimore, Md.

Engineers' Club of Minneapolis, 17 South Sixth Street, Minneapolis, Minn.

Engineers' Club of Philadelphia, 1317 Spruce Street, Philadelphia, Pa.

Engineers' Club of St. Louis, 3817 Olive Street, St. Louis, Mo.

Engineers' Club of Toronto, 96 King Street, West, Toronto, Ont., Canada.

Engineers' Society of Pennsylvania, 219 Market Street, Harrisburg, Pa.

Engineers' Society of Western Pennsylvania, 803 Fulton Building, Pittsburg, Pa.

Institute of Marine Engineers, 58 Romford Road, Stratford, London, E., England.

Institution of Engineers of the River Plate, Buenos Aires, Argentine Republic.

Institution of Naval Architects, 5 Adelphi Terrace, London, W. C., England.

Junior Institution of Engineers, 39 Victoria Street, Westminster, S. W., London, England.

Koninklijk Instituut van Ingenieurs, The Hague, The Netherlands.

Louisiana Engineering Society, 321 Hibernia Bank Building, New Orleans, La.

Memphis Engineering Society, Memphis, Tenn.

Midland Institute of Mining, Civil and Mechanical Engineers, Sheffield, England.

Montana Society of Engineers, Butte, Montana.

North of England Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne, England.

Oesterreichischer Ingenieur= und Architekten=Verein, Eschenbachgasse 9, Vienna, Austria.

Pacific Northwest Society of Engineers, 803 Central Building, Seattle, Wash.

Rochester Engineering Society, Rochester, N. Y.

Sachsischer Ingenieur= und Architekten=Verein, Dresden, Germany.

Sociedad Colombiana de Ingenieros, Bogota, Colombia.

Societe des Ingenieurs Civils de France, 19 Rue Blanche, Paris, France.

Society of Engineers, 17 Victoria Street, Westminster, S. W., London, England.

Svenska Teknologforeningen, Brunkebergstorg 18, Stockholm, Sweden.

Tekniske Forening, Vestre Boulevard 18–1, Copenhagen, Denmark.

Western Society of Engineers, 1737 Monadnock Block, Chicago, Ill.

SEARCHES IN THE LIBRARY

In January, 1902, the Secretary was authorized to make searches in the Library, upon request, and to charge therefor the actual cost to the Society for the extra work required. Since that time many searches have been made, and bibliographies and other information on special subjects furnished.

The resulting satisfaction, to the members, who have made use of the resources of the Society in this manner, has been expressed frequently, and leaves little doubt that, if it were generally known to the membership that such work would be undertaken, many would avail themselves of it.

The cost is trifling compared with the value of the time of an engineer who looks up such matters himself, and the work can be performed quite as well, and much more quickly, by persons familiar with the Library.

In asking that such work be undertaken, members should specify clearly the subject to be covered, and whether references to general

books only are desired, or whether a complete bibliography, involving search through periodical literature, is desired.

In reference to this work, the Appendix* to the Annual Report of the Board of Direction for the year ending December 31st, 1906, contains a summary of all searches made to that date.

LOCAL ASSOCIATIONS OF MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Colorado Association

(Abstract of Minutes of Meeting)

January 15th, 1910.—The regular meeting of the Colorado Association of Members, Am. Soc. C. E., was called to order at 8.30 P. M.; President H. S. Crocker in the chair; H. J. Burt, Secretary; and present, also, 19 members and 13 guests.

The minutes of the December meeting were read and approved.

On motion, duly seconded, it was ordered that the Chair appoint a committee of three or five members to act in co-operation with the Committee of the Colorado Bar Association on proposed legislation in relation to drainage, and that the Committee be empowered to report to the Association upon any legislation that may affect the interests of the Engineering Profession.

Charles W. Comstock, M. Am. Soc. C. E., read a paper on "Engineering Education," which was discussed by Messrs. Lory, Carpenter, Allison, Haldan, Smith, Lyon, Anderson, and the author.

Adjourned.

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* *Proceedings*, Vol. XXXIII, p. 20 (January, 1907).

ACCESSIONS TO THE LIBRARY

(From January 12th to February 7th, 1910)

DONATIONS*

GAS, GASOLINE, AND OIL-ENGINES, INCLUDING PRODUCER-GAS PLANTS.

A Complete and Practical Work, Fully Describing and Illustrating the Theory, Design, Construction, and Management of the Explosive Motor for Stationary, Marine and Vehicle Motor Power. By Gardner D. Hiscox. Eighteenth Edition, Revised and Enlarged. Cloth, 9¼ x 6¼ in., illus., 476 pp. New York, The Norman W. Henley Publishing Company, 1910. $2.50 net.

In the present edition of this book, the author's preface states that much new matter has been added, especially in the Marine Department, and the rules and regulations formulated by the insurance interests for the safe installation of gasoline motors and producer-gas plants are also given. A list of United States patents issued on the gas-engine industry from 1875 to October 1st, 1909, is added at the end of the volume. The Contents are: Introduction; Theory of the Gas and Gasoline Engine; The Utilization of Heat and Its Efficiency in Explosive Motors; Retarded Combustion, Wall-Cooling, and Compression Efficiencies; Compression in Explosive Motors, and Its Work; Causes of Loss and Inefficiency in Explosive Motors; Economy of the Gas Engine for Electric Lighting, etc.; The Material Power in Explosive Engines; Carburetters; Cylinder Capacity of Gas and Gasoline Engines; Governors and Valve Gear; Explosive Motor Ignition; Cylinder Lubricators and Mufflers; Construction Details and Parts of the Explosive Motor; Explosive Motor Dimensions; Types and Details of the Explosive Motor; The Measurement of Power; Management of Explosive Motors; Explosive Engine Testing; The Amateur's Motor; Marine Motors; Motor Bicycles, Tricycles and Automobiles; Kerosene Distilling and Petroleum Oil Motors; Producer Gas and Its Production; Index.

HENLEY'S ENCYCLOPEDIA OF PRACTICAL ENGINEERING AND ALLIED TRADES, VOL. V.

A Practical and Indispensable Work of Reference for the Mechanical Engineer, Designer, Draftsman, Shop Superintendent, Foreman, and Machinist. Edited by Joseph G. Horner, A. M. Inst. M. E. Half Morocco, 7½ x 9 in., illus. New York, The Norman W. Henley Publishing Co., 1909. $6 per vol., or $25 for set of 5 vol.

This volume is the last of the set of five which comprise the whole work, the first having been published in 1906. The sub-title describes the publication as encyclopedic in scope, thorough and practical in its treatment of technical subjects, simple and clear in its descriptive matter, and without unnecessary technicalities or formulas. The articles are said to be as brief as may be and yet give a reasonably clear and explicit statement of the subject, and to be written by men who have had ample practical experience in the matters of which they write. The work is freely illustrated with working drawings, diagrams and photographs, and many cross-references are used to facilitate the work of those looking up any subject.

THE FLOW OF WATER.

A New Theory of the Motion of Water Under Pressure and in Open Conduits, and Its Practical Application. By Louis Schmeer. Cloth, 9 x 6 in., illus., 6 + 228 pp. New York, D. Van Nostrand Company, 1909. $3.00 net.

The author states that this work is the outcome of a series of investigations begun several years ago with the object of finding a simple expression for the phenomenon of flow in irrigation channels, and he expresses the hope that the volume will be useful to the practical engineer. The Contents are: Introduction; Primary Laws of Pressure and Fall; Primary Laws of Fluid Friction; Distribution of Head; Distribution of Energy; The Coefficient c in the Formula $v = c\sqrt{rs}$;

*Unless otherwise specified, books in this list have been donated by the publisher.

Primary Determination of the Coefficient *c*; Mathematical Expressions for the Variation of the Coefficient *c*; The Resistance Due to Curves; The Resistances Due to Entrances, Elbows, etc.; Riveted Conduits; Practical Application of the Formula; Values of *a*, the Coefficient of Variation of *c*; Values of the Coefficients *c* and *f* for Conduits Under Pressure; Loss of Head in Welded Conduits; Diameters, Internal Areas, Radii and Their Roots; Roots of Mean Hydraulic Radii; Values of *m* and *K*; The Coefficients Indicating the Degree of Roughness; Alphabetical List of Authorities; Experimental Data; Forms of Sections for Conduits; Sewers; Exponential Equations; Explanation of the Use of the Tables of Velocities and Quantities; Sines of Slopes and Their Roots; Powers of Diameters of Circular Conduits; Powers of Mean Hydraulic Radii or of Depths of Water in the Form of Section Most Favorable to Flow; Quantities of Discharge in Cubic Feet per Second of a Conduit One Foot in Diameter; Velocity of Flow in a Semi-Square 1 Foot Deep; Discharge of a Semi-Square 1 Foot Deep; Weir Discharges; Weir Formulæ; Methods of Measurement; Surface, Mean and Bottom Velocities; Variation of the Coefficient *c* with the Slope; The Formula in Metric Measure; English and Metric Equivalents; Greatest Efficiency of a Conduit of a Given Diameter as a Transmitter of Energy; Most Economical Diameter of a Conduit Under Pressure; Index.

Gifts have also been received from the following:

Alvord, John V. 1 pam.
Am. Gas Inst. 1 bound vol.
Am. Inst. Elec. Engrs. 1 bound vol.
Am. Inst. Min. Engrs. 1 bound vol.
Am. Mathematical Soc. 2 pam.
Assoc. of Am. Portland Cement Mfrs. 5 pam.
Baltimore & Ohio R. R. 1 pam.
Bilton, H. J. I. 1 pam.
Bombay, India-Public Works Dept. 1 pam.
Canada-Dept. of Marine and Fisheries. 1 pam.
Case School of Applied Sci. 1 pam.
Chemisches Laboratorium für Tonindustrie. 1 bound vol., 2 pam.
Columbia Univ. 2 vol.
Connecticut-R. R. Commrs. 1 bound vol.
Davis, George J., Jr. 1 pam.
Dudley, Charles B. 8 pam.
Engrs.' Club of Cincinnati. 1 pam.
FitzGerald, Desmond. 1 pam.
Fletcher, Robert. 3 pam.
France-Ministère des Travaux Publics, des Postes et des Telegraphes. 4 pam.
Germany - Kaiserliche Generaldirektion der Eisenbahnen in Elsass-Lothringen. 1 pam.
Great Eastern Ry. Co. 1 pam.
Harvard Univ. 1 bound vol.
Institution of Civ. Engrs. 1 bound vol., 3 pam.
London, Brighton & South Coast Ry. Co. 1 pam.
Massachusetts-Board of Harbor and Land Commrs. 1 bound vol.
Metropolitan Ry. Co. 1 pam.
Mott, William E. 1 pam.
National Board of Fire Underwriters. 12 pam.
New York City-Jamaica Bay Impvt. Comm. 1 pam.
New York State-Public Service Comm., First Dist. 4 pam.
New York Univ. 1 bound vol.
Oklahoma, State Univ. of. 1 pam.
Ontario, Canada-Bureau of Mines. 1 pam.
Ontario, Canada-Registrar-General. 1 pam.
Philadelphia, Pa.-Mayor. 3 bound vol.
Poughkeepsie, N. Y.-Board of Public Works. 1 pam.
Queensland, Australia - Harbours and Rivers Dept. 1 pam.
Richmond, Fredericksburg & Potomac R. R. Co. 1 pam.
Rhode Island-State Board of Public Roads. 3 bound vol.
Rugby Eng. Soc. 1 bound vol.
Smithsonian Institution. 1 bound vol., 1 pam.
Trinity Coll. 1 pam.
U. S.-Bureau of Statistics. 2 pam.
U. S.-Chf. of Engrs. 54 pam.
U. S.-Dept. of Agriculture. 1 pam.
U. S.-Nautical Almanac Office. 1 pam.
U. S.-Naval Observatory. 1 pam.
U. S.-Office of the Library and Naval War Records. 4 pam.
U. S.-Technologic Branch, Geol. Survey. 1 pam.
Virginia, Univ. of. 1 pam.
Western Austrialia-Geol. Survey. 1 pam.
Worcester Polytechnic Inst. 1 pam.

BY PURCHASE.

Modern Practice in Mining. Vol. I, Coal, Its Occurrence, Value and Methods of Boring. By R. A. S. Redmayne. Longmans, Green and Co., London, New York, Bombay, and Calcutta, 1908.

Canal Enlargement in New York State, Papers on the Barge Canal Campaign and Related Topics. (Buffalo Historical Society Publications, Vol. 13. Edited by Frank H. Severance.) Buffalo Historical Society, Buffalo, N. Y., 1909.

Minerva, Jahrbuch der Gelehrten Welt. Begründet von Dr. K. Trübner. Neunzehnter Jahrgang, 1909–1910. Karl J. Trübner, Strassburg, 1910.

Train Resistance Bibliography. By F. J. Cole. *Railway Age Gazette*, New York, 1910.

Railway Enterprise in China, an Account of its Origin and Development. By Percy Horace Kent. Edward Arnold, London, 1908.

The Public Health Agitation 1833-48. By B. S. Hutchins. A. C. Fifield, London, 1909.

Mitteilungen über Forschungsarbeiten auf dem Gebiete des Ingenieurwesens Insbesondere aus den Laboratorien der Technischen Hochschulen, Nos. 78-79. Herausgegeben vom Verein Deutscher Ingenieure. Julius Springer, Berlin, 1909.

Moody's Manual of the Railroads and Corporation Securities. Tenth Annual Number. Revised Edition (Revised and Supplementary to Nov. 10th, 1909.) Moody Manual Company, New York, 1909.

SUMMARY OF ACCESSIONS

(From January 12th to February 7th, 1910)

Donations (including 18 duplicates)	155
By purchase	9
Total	164

MEMBERSHIP

ADDITIONS

(January 12th to February 7th, 1910)

MEMBERS		Date of Membership.
BUEHLER, WALTER. Vice-Pres., Kettle River Quarries Co., Minneapolis, Minn.; Address, 6182 Washington Blvd., St. Louis, Mo	Assoc. M. M.	Mar. 7, 1906 Jan. 4, 1910
DALLIS, PARK ANDREW. Mill Archt. and Engr., 1023 Candler Bldg., Atlanta, Ga.	Assoc. M. M.	June 1, 1904 Jan. 4, 1910
DE YOUNG, ISAAC. U. S. Junior Engr., Sault Ste. Marie, Mich	Assoc. M. M.	Dec. 5, 1906 Jan. 4, 1910
FINLEY, EDWIN CLIFFORD. Pres. and Engr., Itawamba Eng. Co., 308 South 8th St., St. Louis, Mo	Assoc. M. M.	April 5, 1905 Nov. 30, 1909
GRAVES, WALTER JOSEPH. U. S. Engr. Office, Sault Ste. Marie, Mich	Assoc. M. M.	July 9, 1906 Jan. 4, 1910
HOOVER, HERBERT CLARK. Red House, Hornton St., London, England		Jan. 4, 1910
HUBBARD, ISAAC WENDELL. (Pugh & Hubbard), 601 Witherspoon Bldg., Philadelphia, Pa	Assoc. M. M.	Mar. 1, 1905 Jan. 4, 1910
MAURICE, GEORGE HOLBROOKE. Prin. Asst. Engr., Board of Public Works, 27 South 2d St., Harrisburg, Pa.		Jan. 4, 1910
REEVES, HARLEY EDSON. U. S. Junior Engr., Atkinson, Ill		Jan. 4, 1910
RHINES, GEORGE VOLNEY. Structural Engr. with Geo. S. Mills, Archt., 1234 Ohio Bldg., Toledo, Ohio	Assoc. M. M.	June 3, 1903 Feb. 1, 1910
ROSENBERG, THEODORE. Cons. Engr. and Archt., Glenwood Springs, Colo		Jan. 4, 1910
ROWELL, GEORGE FREEMAN. Res. Engr., Chattanooga & Tennessee River Power Co., Guild, Tenn	Jun. Assoc. M. M.	May 4, 1897 Jan. 2, 1901 Jan. 4, 1910
SPEAKMAN, RICHARD EDWARD. City Engr., Brandon, Man., Canada		Jan. 4, 1910
TATUM, SLEDGE. Drainage Investigations, U. S. Geological Survey, Washington, D. C		Jan. 4, 1910

ASSOCIATE MEMBERS

BATCHELDER, BENJAMIN FRANKLIN. Potsdam, N. Y	Jan. 4, 1910
BISCHOFF, JULIUS MONTGOMERY. Asst. Engr., Terminal R. R. Assoc., Union Station (Res., 2736 Ann Ave.), St. Louis, Mo	Jan. 4, 1910

ASSOCIATE MEMBERS (*Continued*).

		Date of Membership.
BOLTZ, THOMAS FRANKLIN. Supt., Huron Products Co.; Address, 5428 Catherine St., Philadelphia, Pa.		Oct. 5, 1909
BROGAN, THOMAS BYRNES. Eng. Insp., Board of Water Supply, Headquarters Dept., Distribution Div.; Address, 596 Riverside Drive, New York City		Feb. 1, 1910
CILLEY, MORGAN. Asst. Engr., Bureau of Public Works, Manila, Philippine Islands		Nov. 8, 1909
CONNELL, HENRY LEO. Asst. Engr., Board of Water Supply of New York City, Brown Station, Ulster Co., N. Y.		Jan. 4, 1910
DERR, HOMER MUNRO. Prof. of Civ. Eng., South Dakota State Coll., and Asst. Engr., South Dakota R. R. Comm., Brookings, S. Dak.		Jan. 4, 1910
FORTNEY, CAMDEN PAGE. Superv. of Masonry, Gatun Locks, Gatun, Canal Zone, Panama	Jun. Assoc. M.	Oct. 2, 1906 Nov. 30, 1909
FRASQUIERI Y REGUEIFERO, TRANQUILINO. Havana, Cuba.		Aug. 31, 1909
GREENMAN, RUSSELL SOULE. Res. Engr., Testing Laboratory, Dept. of N. Y. State Engr. and Surv., State Hall, Albany, N. Y.		Aug. 31, 1909
HALE, RICHARD KING. Cons. Engr. (Richardson & Hale), 85 Water St., Boston, Mass.	Jun. Assoc. M.	April 4, 1905 Feb. 1, 1910
HAVENS, RALPH DEWITT. 155 Prospect St., Bristol, Conn.		Aug. 31, 1909
KING, ROY STEVENSON. Mech. Engr., 43 Wroe Ave., Dayton, Ohio		Jan. 4, 1910
KOCH, JOHN CHRISTIAN. 740 West 26th St., Chicago, Ill.		Jan. 4, 1910
LARUE, EUGENE CLYDE. Dist. Engr., Water Resources Branch, U. S. Geological Survey, Box 972, Salt Lake City, Utah		Jan. 4, 1910
LORENZ, GEORGE BENJAMIN. Asst. Engr. with George N. Randle, City Engr., 1826 G St., Sacramento, Cal.		Jan. 4, 1910
MAUGHMER, CARL. 2616 N St., Sacramento, Cal.		Jan. 4, 1910
MULLER, LESLIE. Care, H. & M. R. R., 124 West 31st St., New York City		Feb. 1, 1910
PIRES DO RIO, JOSÉ. 93 Rua Quitanda, Rio de Janeiro, Brazil		Jan. 4, 1910
RANNEY, CHARLES GARFIELD. Leveler, N. Y. State Eng. Dept., Mohawk, N. Y.	Jun. Assoc. M.	April 30, 1907 Feb. 1, 1910
SOULÉ, EDWARD LEE. Structural Engr. with Jno. B. Leonard, 2330 Durant Ave., Berkeley, Cal.	Jun. Assoc. M.	April 3, 1906 Jan. 4, 1910
SULLIVAN, JOHN FRANCIS. Eng. Dept., Public Service Comm., 1st Dist., 601 West 151st St., New York City		Jan. 4, 1910
TEBBETTS, GEORGE EDWARD. 209 Adams St., Room 62, Chicago, Ill.		Jan. 4, 1910

ASSOCIATE MEMBERS (*Continued*).		Date of Membership.
WILCOCK, FREDERICK. 4 Court Sq., Brooklyn, N. Y.	Jun. Assoc. Assoc. M.	Jan. 7, 1902 Oct. 6, 1903 Jan. 4, 1910
WILCOX, FRANK LESLIE. Hydr. and San. Engr., Security Bldg., St. Louis, Mo.	Jun. Assoc. M.	Sept. 6, 1904 Feb. 1, 1910

ASSOCIATES

ATWELL, HARRY HURD. Instr. in Surv., Univ. of Michigan, 732 Packard St., Ann Arbor, Mich.	Jun. Assoc.	Mar. 31, 1908 Jan. 4, 1910
HOWE, JAMES VANCE. Instr. in Civ. Eng., Missouri School of Mines, Rolla, Mo.; Address, 205 Willey St., Morgantown, W. Va.		Nov. 30, 1909

JUNIORS

EDMUNDSON, HAROLD BOWEN. Care, State Board of Public Roads, Providence, R. I.	Nov. 30, 1909
GRAY, HAROLD FARNSWORTH. 2540 Benvenue Ave., Berkeley, Cal.	Jan. 4, 1910
MERRITT, CHARLES EDWARD. 114 South Massey St., Watertown, N. Y.	Jan. 4, 1910
PATTERSON, IRVING WOOSTER. Insp., Rhode Island State Board of Public Roads, 175 Thayer St., Providence, R. I.	Jan. 4, 1910
SEELEY, HENRY ARTHUR. Insp., Reinforced Concrete Bridge, Pequonnock River, 334 Fairfield Ave., Bridgeport, Conn.	Jan. 4, 1910

DEATHS

BUXTON, CLIFFORD. Elected Member, May 6th, 1885; died January 12th, 1910.

EMIGH, JOHN H. Elected Member, April 3d, 1901; died January 6th, 1910.

HUMPHREY, HENRY CYPRIAN. Elected Associate Member, September 4th, 1901; Member, October 3d, 1905; died December 9th, 1909.

KINNEY, EDWARD CORNELIUS. Elected Member, May 3d, 1882; died January 16th, 1910.

PROBASCO, SAMUEL R. Elected Member, November 18th, 1866; died January 19th, 1910.

WHITCOMB, HENRY DONALD. Elected Member, February 21st, 1872; died January 26th, 1910.

Total Membership of the Society, February 7th, 1910,
5 322

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST

(January 11th, to February 7th, 1910)

NOTE.—*This list is published for the purpose of placing before the members of the Society, the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS

In the subjoined list of articles, references are given by the number prefixed to each journal in this list:

(1) *Journal*, Assoc. Eng. Soc., 31 Milk St., Boston, Mass., 30c.
(2) *Proceedings*, Engrs. Club of Phila., 1317 Spruce St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Engrs., Monadnock Blk., Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Canada.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech., Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Inst., Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 25c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 25c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c.
(14) *Engineering Record*, New York City, 12c.
(15) *Railway Age Gazette*, New York City, 15c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Electric Railway Journal*, New York City, 10c.
(18) *Railway and Engineering Review*, Chicago, Ill., 10c.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England, 25c.
(22) *Iron and Coal Trades Review*, London, England, 25c.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gas Light Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World*, New York City, 10c.
(28) *Journal*, New England Water-Works Assoc., Boston, Mass., $1.
(29) *Journal*, Royal Society of Arts, London, England, 15c.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales* de l'Assoc. des Ing. Sortis des Ecoles Spéciales de Gand, Brussels, Belgium.
(32) *Mémoires et Compte Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economiques des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(37) *Revue de Mécanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Proceedings*, Am. Inst. Elec. Engrs., New York City, 50c.
(43) *Annales des Ponts et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governors Island, New York Harbor, 50c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 8c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift*, Verein Deutscher Ingenieure, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Düsseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift*, Oesterreichischer Ingenieur und Architekten Verein, Vienna, Austria.
(54) *Transactions*, Am. Soc. C. E., New York City, $4.
(55) *Transactions*, Am. Soc. M. E., New York City, $10.
(56) *Transactions*, Am. Inst. Min. Engrs., New York City, $5.

(57) *Colliery Guardian*, London, England.
(58) *Proceedings*, Engrs.' Soc. W. Pa., 803 Fulton Bldg., Pittsburg, Pa., 50c.
(59) *Transactions*, Mining Inst. of Scotland, London and Newcastle-upon-Tyne, England.
(60) *Municipal Engineering*, Indianapolis, Ind., 25c.
(61) *Proceedings*, Western Railway Club, 225 Dearborn St., Chicago, Ill., 25c.
(62) *Industrial World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E., London, England.
(64) *Power*, New York City, 20c.
(65) *Official Proceedings*, New York Railroad Club, Brooklyn, N. Y., 15c.
(66) *Journal of Gas Lighting*, London, England, 15c.
(67) *Cement and Engineering News*, Chicago, Ill., 25c.
(68) *Mining Journal*, London, England.
(70) *Engineering Review*, New York City, 10c.
(71) *Journal*, Iron and Steel Inst., London, England.
(71*a*) *Carnegie Scholarship Memoirs*, Iron and Steel Inst., London, England.
(73) *Electrician*, London, England, 18c.
(74) *Transactions*, Inst. of Min. and Metal., London, England.
(75) *Proceedings*, Inst. of Mech. Engrs., London, England.
(76) *Brick*, Chicago, Ill., 10c.
(77) *Journal*, Inst. Elec. Engrs., London, England.
(78) *Beton und Eisen*, Vienna, Austria.
(79) *Forscherarbeiten*, Vienna, Austria.
(80) *Tonindustrie Zeitung*, Berlin, Germany.
(81) *Zeitschrift für Architektur und Ingenieurwesen*, Wiesbaden, Germany.
(83) *Progressive Age*, New York City, 15c.
(84) *Le Ciment*, Paris, France.
(85) *Proceedings*, Am. Ry. Eng. and M. of W. Assoc., Chicago, Ill.
(86) *Engineering-Contracting*, Chicago, Ill., 10c.
(87) *Roadmaster and Foreman*, Chicago, Ill., 10c.
(88) *Bulletin* of the International Ry. Congress Assoc., Brussels, Belgium.
(89) *Proceedings*, Am. Soc. for Testing Materials, Philadelphia, Pa.
(90) *Transactions*, Inst. of Naval Archts., London, England.
(91) *Transactions*, Soc. Naval Archts. and Marine Engrs., New York City.
(92) *Bulletin*, Soc. d'Encouragement pour l'Industrie Nationale, Paris, France.
(93) *Revue de Métallurgie*, Paris, France, 4 fr. 50.
(94) *The Boiler Maker*, New York City, 10c.
(95) *International Marine Engineering*, New York City, 20c.
(96) *Canadian Engineer*, Toronto, Canada, 15c.
(97) *Turbine*, Berlin, Germany. 1 Mark.
(98) *Journal*, Engrs. Soc. Pa., 219 Market St., Harrisburg, Pa., 30c.
(99) *Proceedings*, Am. Soc. of Municipal Improvements, New York City, $1.
(100) *Professional Memoirs*, Corps of Engrs., U. S. A., Washington, D. C., $1.
(101) *Metal Worker*, New York City, 10c.

LIST OF ARTICLES

Bridges.

The Fades Viaduct.* (11) Dec. 31.
Road-Bridge over the Klang River, Federated Malay States.* (11) Jan. 7.
The Mulberry St. Reinforced-Concrete Viaduct, Harrisburg, Pa.* (13) Jan. 13.
The Clinton Bridge of the Chicago & North Western.* (15) Jan. 14.
Reinforced Concrete on the Vandalia Railroad, U. S. A.* E. R. Matthews, A. M. Inst. C. E. (11) Jan. 14.
Launching the Reventazon Bridge, Costa Rica.* (14) Jan. 15.
Rapid Deterioration of Steel Work from the Corrosive Action of Locomotive Gas, McCallie Avenue Bridge, Chattanooga, Tennessee. Robert Hooke. (Abstract of Report to the City Council.) (13) Jan. 20.
The Liao River Railway Bridge, Manchuria. (11) Jan. 21.
The Erection of the Brandywine Viaduct.* (14) Jan. 22.
Design of Combination Timber, Steel and Reinforced Concrete Caissons for the McKinley Bridge, with Some Data on Methods and Rates of Sinking. C. E. Chase. (Abstract from *Cornell Civ. Engr.*) (86) Jan. 26.
Long Span Reinforced-Concrete Girder Bridges.* F. W. Scheidenhelm. (13) Jan. 27.
The Cost of Bridge Floors, Jack Arch Construction.* (12) Jan. 28.
Harlem River Branch Improvements; New York, New Haven & Hartford.* (15) Serial beginning Jan. 28.
The Design of the Evanston Subway Bridges, Chicago, Milwaukee & St. Paul Railway.* E. O. Greifenhagen. (14) Jan. 29.
Emergency Repairs to a Bascule Drawbridge over the Chicago River; Chicago Terminal Transfer Ry.* F. H. Avery. (13) Feb. 3.

*Illustrated.

Bridges—(Continued).

Queensboro Bridge Illumination.* (27) Feb. 3.
Some Cost Data for Reinforced-Concrete Highway Bridges.* A. N. Johnson. (Paper read before the Ill. Soc. of Engrs. and Survs.) (14) Feb. 5; (86) Feb. 2.
The Construction of the Evanston Subway Bridges, Chicago, Milwaukee & St. Paul Railway.* E. O. Greifenhagen. (14) Feb. 5.
A Pier Type of Abutment for Highway Bridges.* (14) Feb. 5.
Great Bridge over the Red River at Indo-China.* (19) Feb. 5.
Le Renforcement du Pont de Benha (sur le Nil).* A. Husson. (43) Nov.
Note sur la Réfection du Pont au-dessus du Chemin de Grande Communication No. 90 de Boves à Ailly-sur-Noye.* H. Bouchard. (38) Jan.

Electrical.

Electricity Works and Refuse Destructors.* J. A. Robertson. (77) Dec.
Some Tests and Uses of Condensers.* W. W. Mordey. (77) Dec.
Some Considerations in the Manipulation of Dry Core Telephone Cables.* F. G. C. Baldwin. (77) Dec.
The Design of Small Direct-Current Machines.* B. E. Stott and J. Hargrove. (77) Dec.
Notes on the Elimination of Sparking.* Laurence H. A. Carr. (77) Dec.
The Direct-Current Variable-Speed Motor and its Application to Modern Machine Tools.* W. Stanley Lonsdale. (77) Dec.
The Radio-Telegraphic Station at Cullercoats.* Aage S. M. Sörensen. (77) Dec.
The Working Limit in Electrical Furnaces due to the "Pinch" Phenomenon.* Carl Hering. (Abstract of paper read before the Amer. Electro-chemical Soc.) (73) Dec. 31.
Stepney Borough Central Station.* (27) Jan. 13.
An Alaskan Hydroelectric Development.* M. Adler. (27) Jan. 13.
The Wireless Telephone. John L. Hogan, Jr. (27) Jan. 13.
Motor Loads and Incomes.* Alton D. Adams. (27) Jan. 13.
Peukert's High-Frequency Generator for Wireless Telegraphy on the Quenched Spark Method.* L. H. Walter. (73) Jan. 14.
Wireless Signaling in Aeronautics, Experiments of the Signal Corps. F. H. McLean. (19) Jan. 15.
Juniata Water & Water-Power Company.* (27) Jan. 20.
The Ottawa Electric Company.* (96) Jan. 21.
Condenser Telephones.* C. Karl Ort and Josef Rieger. (Tr. from *Elektechn. Zeit.*) (73) Jan. 21.
Electric Cables.* F. Fernie. (73) Serial beginning Jan. 21.
Transmission Lines of the Central Colorado Power Company.* (27) Jan. 27.
A Large Industrial Plant Switchboard. Warren H. Miller. (27) Serial beginning Jan. 27.
The Tate Bifunctional Accumulator Plate.* Harry H. Morrell. (96) Jan. 28.
Central Stations Versus Isolated Plants for Textile Mills. Charles T. Main. (42) Feb.
The Supply of Electrical Power for Industrial Establishments from Central Stations. R. S. Hale. (42) Feb.
Illumination for Industrial Plants. G. H. Stickney. (42) Feb.
A Modern Automatic Telephone Apparatus.* W. Lee Campbell. (42) Feb.
The Applicability of Electrical Power to Industrial Establishments. Dugald C. Jackson. (42) Feb.
Cost of a Construction Service Telephone Line in Cuba.* (86) Feb. 2.
Generating Station of the Sayre Electric Company.* (27) Feb. 3.
Electricity on an Illinois Farm.* (27) Feb. 3.
Les Installations Hydro-Electriques du Sud-Ouest de la France.* P. Postel-Vinay. (32) Nov.

Marine.

The Advance of Marine Engineering in the Early Twentieth Century.* Arthur J. Maginnis. (75) July, 1909.
The New Queenborough and Flushing Mail Steamers.* (11) Jan. 14.
The Brazilian Battleship *Minas Geraes*.* (11) Jan. 21.
A Large Elevator Dredge for Work in Boston Harbor.* (13) Jan. 27.

Mechanical.

The Determination of the Economy of Reversing Rolling-Mills.* C. A. Ablett, A. M. Inst. C. E. (71) Vol. 80.
Economics of Medium-Sized Power Stations; a Study of Comparisons between Steam, Gas and Oil Engines.* A. J. J. Pfeiffer. (77) Vol. 43.
Electrical Operation of Textile Factories.* Herbert W. Wilson. (75) July, 1909.
Indicating of Gas-Engines.* Frederic W. Burstall. (75) July, 1909.
The Utilization of Exhaust Steam for Electric Driving.* C. S. Richards. (77) Dec.

*Illustrated.

Mechanical—(Continued).

Steam Wagons. J. C. Cornock, A. M. Inst. C. E. (Abstract of paper read before the Soc. of Engrs.) (47) Dec. 31.
Rope-Driving.* J. Stormonth. (11) Dec. 31.
The Shaw Process for Making Brick.* (76) Jan.
The Manufacture of Tool Steel.* (41) Jan.
Strasburg Gas Works and Supply.* (66) Serial beginning Jan. 4.
The Need for a Calorific Standard. Henry C. Hazzard. (Abstract of report to the Public Service Comm.) (66) Jan. 4.
The Electrical Equipment of the Great Eastern Railway Co.'s Quay at Parkeston, Harwich.* (73) Jan. 7.
The Design of Aeroplane Engines.* (11) Jan. 7.
Waygood's Electric and Hydraulic Luffing Wharf-Cranes.* (11) Jan. 7.
A New Oil Engine of Remarkably High Economy.* (13) Jan. 13.
Coal Hauling by Automobile Truck: Record of Performance and Costs. (13) Jan. 13.
Wheel Spoil Transporter.* (22) Jan. 14.
Strength of Leather Belts.* Y. Sekiguchi. (47) Jan. 14.
Report of Committee on Calorimetry. (Amer. Gas Inst.)* (24) Jan. 17; (83) Feb. 1
Gas-Producer Plant vs. Central-Station Service for Charging Electric Vehicles Roderick D. Donaldson. (27) Jan. 20.
The Rateau Centrifugal Air Compressors and Blowers.* Frank Koester, Assoc. Am. Inst. E. E. (13) Jan. 20.
A New Design of Steam Pile Driver: Comparisons of Several Types of Drivers.* A. A. Goubert, M. Am. Soc. M. E. (13) Jan. 20.
Influence of High-Speed Steel on Recent Machine Tool Design. O. M. Becker. (47) Jan. 21.
The Diameter of Condenser Tubes.* R. M. Neilson. (12) Jan. 21.
Foundry Plant and Machinery.* Joseph Horner. (11) Serial beginning Jan. 21.
The Electric Motor in Printing Work.* S. H. Sharpsteen. (27) Jan. 27.
The Development of Traction Engines. W. F. McGregor, Jun. M. Am. Soc. M. E. (Abstract of paper read before the Amer. Soc. of Agri. Engrs.) (13) Jan. 27.
The "Louis Bansart" Coke Ovens, with or without Recovery of By-Products.* (22) Jan. 28.
The Application of the Steam Turbine to the Driving of Textile Mills.* G. B. Storie. (Paper read before the Manchester Assoc. of Engrs.) (47) Serial beginning Jan. 28; (12) Jan. 28.
Central Stations Versus Isolated Plants for Textile Mills. Charles T. Main. (42) Feb.
Stacks for Water-Tube Boilers. T. F. J. Maguire. (9) Feb.
Concrete Coke-Oven Construction.* E. A. Lee. (45) Feb.
Special Types of Traction Engines.* William Fletcher, M. I. M. E. (10) Feb.
High Pressure Boosting System.* Seth H. Ely. (83) Feb. 1.
The Sewells Point Coal Pier, Virginian Railway.* (14) Feb. 5.
Sur la Forme Concave à Donner à la Voilure d'un Aéroplane du Côté du Bord d'Attaque.* F. Chaudy. (32) Oct.
Observations sur les Sables de Fonderie. Henry Le Chatelier. (93) Dec.
Résistance d'Anneaux et de Demi-Anneaux Circulaires, Sollicités par un Effort Unique de Traction ou de Compression Centrale.* A. Rauber. (37) Dec. 31.
Dispositif Cinématique pour Moteurs à Gaz à Simple Effet, Quatre Temps.* E.-L. Doaré. (37) Dec. 31.
Les Entrainements d'Eau dans les Générateurs de Vapeur.* M. Emanaud. (34) Serial beginning Jan.
Automobiles à Trolley Aérien Système Mercédès Electrique Stoll.* Enrique Hauser. (33) Jan. 8.
Transmission à Air Comprimé, Système Hautier pour Véhicules Industriels (Poids Lourds).* L. Pierre-Guédon. (33) Jan. 15.

Metallurgical.

Production of Iron and Steel by the Electric Smelting Process.* E. J. Ljungberg. (71) Vol. 80.
The "Growth" of Cast Irons after Repeated Heatings.* H. F. Rugan, M. A. S. M. E., and H. C. H. Carpenter. (71) Vol. 80.
Uniform Moisture in Blast, Experiment Carried out at Clarence Ironworks, 1909.* Greville Jones. (71) Vol. 80.
The Fuel Economy of Dry Blast as Indicated by Calculations from Empirical Data.* R. S. Moore. (71) Vol. 80.
Artificial Magnetic Oxide of Iron. F. J. R. Carulla. (71) Vol. 80.
The Constitution of Carbon-Tungsten Steels.* Thomas Swinden. (71) Vol. 80.
Blast Furnace No. V, of the Alexandrovsky Works, South Russia. M. A. Pavloff. (12) Jan. 21.
Cyaniding at the Montgomery-Shoshone Mill.* P. Edwin Van Saun. (16) Jan. 22.
All Slime Treatment of Ore in Cyanide Plants. H. A. Megraw. (16) Feb. 5.
La Métallurgie aux Congrès de Londres (Juin 1909) et de Copenhague (Septembre 1909). L. Guillet. (32) Oct.

*Illustrated.

Metallurgical—(Continued).

L'Industrie de l'Aluminium en France.* R. Pitaval. (32) Nov.
Four Electrique.* O. Boudouard. (92) Dec.
Expériences sur la Dureté des Aciers Trempés et Particulièrement sur la Dureté des Aciers Cémentés et Trempés.* A. Portevin et H. Berjot. (93) Jan.
Détermination des Points de Transformation des Alliages Cu-Al (8-15, 5% Al) (Etude de la Variation de la Résistance Electrique avec la Température.* Maurice Barrée. (93) Jan.
Etude des Gaz Dégagés par l'Action des Sels Cuivriques sur les Aciers.* E. Goutal. (93) Jan.
Phénomène de Décantation au Four Electrique.* Ch. Clausel de Coussergues. (93) Jan.

Military.

Gun-Cotton Charges.* (11) Jan. 28.
What Smokeless Powder has Made Possible.* Robert G. Skerrett. (46) Serial beginning Feb. 5.

Mining.

Coal Cutting Machinery.* Robert Peele. (6) Nov.
Mine Accident Investigations of the United States Geological Survey.* George S. Rice. (4) Dec.
The Use of Electricity in Fiery Mines.* (22) Serial beginning Jan. 7.
The Construction of Cage Guides in Coal Pits.* (Abstract of Report of the Royal Comm. of Mines.) (47) Jan. 7.
Electric Haulage at the Loftus Iron-Stone Mines.* (12) Jan. 7.
Electric Plant for Collieries.* (57) Jan. 7.
Coal Screening and Washing Plant with Coking Coal Bunkers at the Bergmannsglueck Colliery of the Royal Mining Inspection III at Buer in Westphalia.* (22) Jan. 7.
Locomotives vs. Stationary Hoisting Engines for Raising Material in Open Cut Mines. J. F. Jackson, Assoc. M. Am. Soc. C. E. (13) Jan. 13.
Electrical Haulage Installation at the Loftus Ironstone Mines.* (26) Jan. 14.
Gravel Washing Plant.* (14) Jan. 15.
Analysis of Mine and Mill Practice on Rand. E. M. Weston. (16) Serial beginning Jan. 15.
Method of Making a Blast Displacing 180 000 Tons of Rock, with Some Costs. (86) Jan. 19.
Circular vs. Rectangular Shaft Sinking.* Henry M. Payne. (16) Jan. 22.
Firing Shots in Mines by Electricity.* Sydney F. Walker. (16) Jan. 22.
Mining in Siberia.* R. M. Percy. (22) Jan. 28.
Wire Ropes in Colliery Practice.* R. H. Rowland. (16) Jan. 29.
A Composite Mine Car.* Wm. Archie Weldin. (45) Feb.
Mining Coal with Explosives.* (45) Feb.
Modern Rock Drilling.* (45) Feb.
The Cherry Mine Disaster.* (45) Feb.
The Keedy Sizer for Classifying Complex Ores.* Carl F. Dietz and Dyke V. Keedy. (16) Feb. 5.
Equipment and Methods at the Hecla Mine.* Roy Hutchins Allen. (16) Feb. 5.

Miscellaneous.

A New Explosives Ordinance for the City of Chicago. (13) Jan. 13.
Logarithmic Diagrams Based on Isoplethe Points.* H. A. Gehring. (14) Jan. 15.
Le Bassin Houiller Blanzy-Auxonne-Ronchamp.* Eugène Léotard. (32) Oct.
Compte Rendu Technique des Excursions de la Société des Ingénieurs Civils de France en Juillet 1909; Visites Industrielles à Paris, Exposition de Nancy, Bassin de Briey.* J. Bergeron. (32) Oct.
Evaluation du Froid Obtenu dans une Détente Effectuée sans Travail Extérieur Sensible.* C. Monteil. (32) Nov.

Municipal.

Construction and Wear of Roads. Henry Reginald Arnulph Mallock. (63) Vol. 178.
Street Lighting. E. N. Wrightington. (Abstract of paper read before the National Commercial Gas Assoc.) (66) Jan. 4; (83) Feb. 1.
Economics of Street Pavements. S. Whinery. (Abstract from report to the Finance Comm. of Boston.) (86) Jan. 12.
Vitrified Clay Curbing for Streets and Roads.* (13) Jan. 13.
Ottawa Civic Works.* Newton J. Ker. (96) Jan. 21.
Cost of Constructing a Macadam Pavement with Concrete Curb and Gutter, Manistee, Mich. (86) Jan. 26.
Relative Cost of Municipal Work Done by Day Labor and Contract. Harrison P. Eddy. (Paper read before the Amer. Assoc. for the Advancement of Sci.) (86) Jan. 26; (60) Feb; (13) Jan. 27.
Road Construction and Maintenance in Cumberland County, England. George Joseph Bell, M. Am. Soc. C. E. (13) Jan. 27.
Bituminous Highway Construction. Clarence A. Kenyon. (Paper read before the Ind. Eng. Soc.) (60) Feb.

*Illustrated.

Municipal—(Continued).

Methods and Costs of Sidewalk Construction in Chicago. N. E. Murray. (Abstract of paper read before the Ill. Soc. of Engrs. and Survs.) (86) Feb. 2.

Detailed Cost of Constructing 2 070 Sq. Yds. of Brick Pavement at Carlisle, Pa. C. A. Bingham, Assoc. M. Am. Soc. C. E. (86) Feb. 2.

The Water Supply, Sewerage and Subways of Paris in Relation to the Present Floods.* Geo. A. Soper, M. Am. Soc. C. E. (13) Feb. 3.

Railroads.

The Construction of the Ninth Division (Hills Section) of the Assam-Bengal Railway.* Thomas Richard Nolan, Assoc. M. Inst. C. E. (63) Vol. 178.

Stuartstown Narrow-Gauge Railway, Natal.* Walter Sweetman, Assoc. M. Inst. C. E. (63) Vol. 178.

The Serviceable Life and Cost of Renewals of Permanent Way of British Railways.* R. Price-Williams. (71) Vol. 80.

Locomotives Designed and Built at Horwich, with Some Results.* George Hughes. (75) July, 1909.

Single-Phase Railways.* Percy C. Jones. (77) Dec.

Comparative Cost of Traction Systems. O. Tissot. (Abstract of Report to the Inter. Cong. on the Application of Elec., 1908.) (73) Dec. 31.

Notes on Locomotives.* (21) Jan.

The T. A. C. System of Train Lighting.* (21) Jan.

Italian Goods Locomotives and their Working.* (21) Jan.

Engineering Construction on the Southern Ry.* (18) Serial beginning Jan. 8.

Original Cost and Cost of Reproduction of the Northern Pacific Railway (1 645 miles) in the State of Washington. (86) Jan. 12.

Coal Cars and Coal Trains of the Virginian Ry.* (13) Jan. 13.

Comparative Tests of Consolidation and Mallet Locomotives on Southern Pacific.* (15) Jan. 14.

Three-Cylinder Shunting Locomotive; North-Eastern Railway.* (11) Jan. 14.

The Visalia Fifteen-Cycle Single-Phase Railway.* (17) Jan. 15.

A Railway Ditching Machine for Small Cuts and Fills.* (13) Jan. 20.

Experience with Pipe Culverts of Corrugated Iron.* (13) Jan. 20.

A Large Gasoline Motor Car for the Oregon Short Line Ry.* (13) Jan. 20.

Tender of 12 000 Gallons Capacity for Mallet Locomotives, Atchison, Topeka & Santa Fé.* (15) Jan. 21; (13) Jan. 27.

New Passenger Engines for the Chicago & Northwestern Ry.* (18) Jan. 22.

Woodford Haulage System in Earth Moving Operations.* (18) Jan. 22.

The Scherl Gyroscopic Monorail Car, the Principle of Its Operation.* (46) Jan. 22; (15) Jan. 21; (13) Jan. 27.

Evanston Track Elevation, Chicago, Milwaukee & St. Paul Ry. E. O. Greifenhagen. (14) Serial beginning Jan. 22.

Important New Work of the Illinois Traction System.* (17) Jan. 22.

The Copper River & Northwestern Railway.* (14) Jan. 22.

The Tractive Power of Simple and Compound Locomotives.* Sidney C. Carpenter. (15) Jan. 28.

Hopper-Ballast Wagons on the Queensland Railways.* (11) Jan. 28.

New Consolidation Locomotives for the Chicago & Northwestern Ry.* (18) Jan. 29.

The International Track Ballasting Machine.* (18) Jan. 29.

Lewiston, Augusta & Waterville Street Railway.* (17) Jan. 29.

Financial Aspect of the Application of Electric Motive Power to Railroads. F. Darlington. (9) Feb.

The Electrification of Trunk Lines.* L. R. Pomeroy. (25) Feb.

Ten-Wheel Passenger Locomotive, with Emerson Superheater, and Consolidation Locomotive, Chicago Great Western Railway. (25) Feb.

The Brennan Gyroscope, a Non-Mathematical Explanation.* A. F. Dickinson. (10) Feb.

Design of Engine Drop Pit and Table in Round-House of the Central of Georgia.* (15) Feb. 4.

New Shops of Central of Georgia, at Macon, Ga.* (15) Feb. 4.

Tool Lay-Out for the Scranton Shops of the Delaware, Lackawanna & Western.* George L. Fowler. (15) Feb. 4.

Pennsylvania Railroad Specifications for Steel Boiler Tubes and Safe Ends (Locomotives).* (15) Feb. 4.

Note sur les Difficultés de Raccordement et d'Echange du Matériel entre les Chemins de Fer à Voie de 1 Mètre.* Pellarin. (43) Nov.

Etude Expérimentale de la Résistance Vive à la Traction des Attelages de Wagons.* Ch. Frémont. (92) Nov.

Note sur la Tenue des Chaudières de Locomotive à Voie Etroite. Fermé. (37) Dec. 31.

Bascule pour le Pesage des Locomotives, Système Carl Schenck. (34) Jan.

Note sur les Chemins de Fer de l'Afrique Occidentale Française.* R. Godfernaux. (38) Jan.

La Traction Electrique sur le Nouveau Boulevard Lille-Roubaix-Tourcoing.* A. Bidault des Chaumes. (33) Jan. 1.

Locomotive Compound à Bogies Moteurs et à Chaudière Indépendante, Système Garratt des Chemins de Fer de l'Etat de Tasmanie.* (33) Jan. 8.

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*Illustrated.

Railroads, Street.

Railless Electric Traction.* R. Lonneman. (10) Feb.
Trackless Trolley Lines in Austria.* (17) Feb. 5.
Paris and Its Tunnels.* (19) Feb. 5.
A New Storage Battery Street Car.* (46) Feb. 5; (17) Jan. 29.
Le Chemin de Fer Métropolitain de Paris, Ligne No. 6, du Cours de Vincennes à la Place d'Italie.* J. Hervieu. (35) Serial beginning Jan.

Sanitation.

Notes on the Automatic Revolving Sewage-Distributors at the Derby Sewage-Disposal Works.* Arthur Percy Maddocks, Assoc. M. Inst. C. E. (63) Vol. 178.
Electricity Works and Refuse Destructors.* J. A. Robertson. (77) Dec.
Ozone: Its Electrical Production and Use. A Mabille. (26) Dec. 31.
Steam-Heating Installation in the Biology and Geology Building and the Vivarium Building, Princeton University.* (70) Jan.
Plumbing the New Carnegie Swimming Pool and Enclosing Building, Yale University, New Haven, Conn.* (70) Jan.
Formulas for the Capacity of Tile Drains.* E. A. Hamilton. (Abstract of paper read before the Amer. Soc. of Agri. Engrs.) (86) Jan. 12.
The Work of Brick Masons at Boston (Sewers). (14) Jan. 15.
Sewage Disposal Works at the Danville State Hospital.* (14) Jan. 15.
Public Comfort Stations in Newark, N. J.* (101) Jan. 15.
Interesting Factory Ventilating Plant.* R. T. Coe. (101) Jan. 15.
Central Steam Distribution from Hilltop; High-Pressure Steam Supplied to the Numerous Scattered Buildings at Johnson City, Tenn.* (101) Serial beginning Jan. 15.
A Remarkable Theatre Ventilating Plant.* (101) Jan. 15.
Disposal of Manufactural Wastes and Sewage at Gloversville.* (14) Serial beginning Jan. 22.
A Comprehensive Sewer System for Kansas City, Mo.* Jean Bart Balcomb. (13) Jan. 27.
Sewage Disposal Works, Grand Canyon, Arizona.* (14) Jan. 29.
Town Scavenging and Refuse Disposal. Hugh S. Watson, A. M. I. C. E. (60) Feb.
Design and Construction of Open Ditches to Reduce Maintenance, with a Description of Methods of Maintenance and Some Costs. E. H. Cowan. (Paper read before the Ill. Soc. of Engrs. and Survs.) (86) Feb. 2.
Methods of Filtering Air. (Abstract of report to Amer. Soc. of Heating and Ventilating Engrs.) (101) Feb. 5.
La Dessiccation Rationnelle des Boues d'Egouts.* M. Bousquet. (34) Jan.

Structural.

The "New York Times" Building. Corydon Tyler Purdy, M. Inst. C. E. (63) Vol. 178.
Experimental Data Bearing upon Properties of Materials Employed in Reinforced Concrete.* Edward William Hollingworth, Assoc. M. Inst. C. E. (63) Vol. 178.
Experimental Data in Regard to Beams and Columns of Reinforced Concrete. Edward William Hollingworth, Assoc. M. Inst. C. E. (63) Vol. 178.
Tests of Cast Iron.* E. Adamson. (71) Vol. 80.
The Action of Air and Steam on Pure Iron.* J. Newton Friend. (71) Vol. 80.
The Corrosion of Iron. J. Newton Friend. (71) Vol. 80.
Reinforced Concrete.* Arthur C. Auden. (75) July, 1909.
A Unique Type of Reinforced Concrete Construction.* Theodore L. Condron. (4) Dec.
The Rolling of Special Sections of Iron and Steel.* Willis McKee. (4) Dec.
The Heat Treatment of Spring Steel.* Lawford H. Fry. (Paper read before the Inter. Assoc. for Testing Materials.) (47) Dec. 31.
A Study of Rust-Preventing Paints for Metal Structures. Emil Camerman. (Paper read before the Inter. Assoc. for Testing Materials.) (47) Dec. 31.
Resistance of Steels to Repeated Alternate Stresses.* James E. Howard. (Paper read before the Inter. Assoc. for Testing Materials.) (47) Dec. 31.
New Cement Mill, near Montreal.* (12) Dec. 31.
The Utilization of Blast-Furnace Slag. G. B. Waterhouse. (67) Jan.
Resistance of Cements to Sea-Water Increased by Admixtures of Puzzuolana. M. R. Feret. (Tr. by W. Michaelis, Jr.) (67) Jan.
Accelerated Method for the Determination of the Resistance of Hydraulic Cements to Sea-Water. M. R. Feret. (Tr. by W. Michaelis, Jr.) (67) Jan.
The Use of Concrete Piles.* Wm. F. Hall. (3) Jan.
The Flexibility of Wire Ropes.* R. W. Chapman. (11) Jan. 7.
Tapering Concrete Chimneys.* (13) Jan. 13.
The Rankine-Gordon and Euler's Formulæ for Columns.* W. E. Lilly. (11) Jan. 14.
The Grand Stand at the Minnesota State Fair Grounds.* (14) Jan. 15.
Economical Selection and Proportion of Aggregates for Portland Cement Concrete. Albert Moyer. (86) Jan. 19.

*Illustrated.

Structural—(Continued).

Processes for the Preservative Treatment of Timber and Approximate Costs of Treatment. G. B. Shipley. (86) Jan. 19.
Installation Cost of a Modern Steam Turbine Plant. (27) Jan. 20.
Approximate Cost of Mill Buildings.* Charles T. Main, M. Am. Soc. C. E. (13) Jan. 27; (14) Jan. 29.
Economical Wood Preservation.* Robert Hays. (15) Jan. 28.
A Large Steel Frame Rolling Mill Building; Special Structural Features of a Recent Addition to the Jones & Laughlin Works.* (14) Jan. 29.
Wood Preservation by the Superficial Method.* (17) Jan. 29.
Interlocking Steel and Concrete Pile Construction for Seawalls and Foundation Work.* (13) Feb. 3.
Treating Timber with Crude Petroleum. C. Marshall Taylor. (Abstract of paper read before the Wood Preservers' Assoc.) (13) Feb. 3.
Fabrication du Sulfure de Zinc et à son Utilisation dans les Travaux de Peinture. Ach. Livat. (92) Nov.
Applications des Méthodes d'Essais Modernes aux Alliages de Cuivre. Léon Guillet et Louis Révillon. (Paper read before the Inter. Assoc. for Testing Materials.) (93) Dec.
Principes Généraux pour les Conditions de Réception du Cuivre. Léon Guillet. (Paper read before the Inter. Assoc. for Testing Materials.) (93) Dec.
Rapports sur les Essais de Métaux par Choc. G. Charpy. (Paper read before the Inter. Assoc. for Testing Materials.) (93) Dec.
Le Phénomène du Durcissement des Agglomérants Hydrauliques Calcaires. W. Michaelis, Aîné. (From *Revue des Matériaux de Construction et de Travaux Publics.*) (84) Serial beginning Dec.
Fabrication Mécanique des Blocs Creux en Mortier de Ciment.* (84) Dec.
Circulaire Ministérielle du 9 Novembre 1909 Relative aux Fournitures de Ciments et Chaux Hydrauliques. (84) Dec.
Sur une Nomenclature Uniforme pour le Fer et l'Acier. Henry M. Howe et Albert Sauveur. (Abstract of paper read before the Inter. Assoc. for Testing Materials.) (93) Jan.

Topographical.

Effect of the Inclination of the Stadia Rod upon Stadia Distances. Boris Levitt. (6) Nov.

Water Supply.

Concrete and Masonry Dam-Construction in New South Wales.* Leslie Augustus Burton Wade, M. Inst. C. E. (63) Vol. 178.
"White Coal" from the Susquehanna.* J. W. Kirkland. (98) Nov.
The Susquehanna River as a Source of Power.* Mason D. Pratt. (98) Nov.
New York City Water Supply.* William W. Brush. (28) Dec.
Ground Waters as Sources of Public Water Supplies. William S. Johnson. (28) Dec.
Report of the Committee on the Depth of Laying Water Pipe (New England Water-Works Assoc.) (28) Dec.
Evaporation from Water Surfaces. Sidney R. Lowcock, M. Inst. C. E. (Abstract of paper read before the Assoc. of Water-Works Engrs.) (66) Jan. 4.
McCall Ferry Hydro-Electric Station.* H. Prime Kieffer. (11) Jan. 7.
The Failure of a Concrete Dam at Dansville, N. Y.* (13) Jan. 13.
The Water Supply Problem of Montreal.* George Janin. (96) Jan. 14.
Inclined Diamond Drill Borings under the Hudson River.* (14) Jan. 15.
The Water Purification Works at Cañon City.* (14) Jan. 15.
A Multiple Arch Dam.* (14) Jan. 15.
An Automatic Fire Pump with Independent Water Supply.* (14) Jan. 15.
Earth and Rock Fill Dam with Concrete Core Wall, Patillas Irrigation Project, Porto Rico.* (86) Jan. 19.
The Great Chaudiere Dam, Ottawa, Ontario.* Douglas L. McLean. (96) Jan. 21.
Hull's Power House.* R. W. Farley. (96) Jan. 21.
Progress on the Ashokan Reservoir.* (14) Jan. 22.
The Water Supply System of Cheyenne, Wyoming.* (14) Jan. 22.
The Deep Well System of Water Supply for South Bend, Ind. Alonzo T. Hammond. (Abstract of paper read before the Indiana Eng. Soc.) (13) Jan. 27; (14) Jan. 29.
The Treatment of Water Antecedent to Filtration.* Walter Clemence, M. I. Mech. E. (11) Serial beginning Jan. 28.
The Design of Pressure Tunnels of the Catskill Aqueduct. (14) Serial beginning Jan. 29.
The Character of Stream Pollution as Affecting Purification Plant Design. H. E. Jordan. (Paper read before the Ind. Eng. Soc.) (60) Feb.
Design of and Method of Constructing a Reinforced Concrete Aqueduct Lining, with Some Data on Costs. (86) Feb. 2.
Recent Records of High-Duty Water-Works Pumping Engines.* (13) Feb. 3.

* Illustrated.

Water Supply—(Continued).

Pigeon Lake Gravity Water Supply.* H. L. Seymour. (Paper read before the Edmonton Eng. Soc.) (96) Feb. 4.
The Maiden Creek Filters, Dam and Conduit at Reading.* (14) Feb. 5.
Valuation of Water Power. (14) Feb. 5.

Waterways.

The Chicago Harbor.* John M. Ewen. (4) Dec.
Recent Improvements at Scarborough Harbour.* (12) Dec. 31.
The Reservoir Possibilities of the Sources of the Mississippi and Tributaries of the Upper Mississippi River with Reference to the Improvement of Navigation.* Charles W. Durham. (13) Jan. 20.
The New Naval Harbor at Dover.* (46) Jan. 22.
Methods and Cost of Constructing a Concrete Lock and Timber Crib Dam with Appurtenant Structures, Employing Day Labor. (86) Serial beginning Jan. 26.
Evaporation from Water Surfaces. Sidney R. Lowcock, M. Inst. C. E. (Abstract of paper read before the Assoc. of Water-Works Engrs.) (66) Jan. 4.
The Reconstruction of the Tyne North Pier.* (12) Jan. 28; (11) Jan. 28.
Substructure of Pier 4, Boston Terminal, Boston & Albany R. R.* (14) Jan. 29.
XIe Congrès International de Navigation tenu à Saint-Pétersbourg en 1908, Rapport des Délégués Français sur les Travaux du Congrès, 2e Section, Navigation Maritime. Babin, Lahaussois, Batard-Razelière, et Ducrocq. (43) Nov.
Le Port du Havre.* A. Guiffart. (33) Serial beginning Jan. 15.

* Illustrated.

Vol. XXXVI. FEBRUARY, 1910. No. 2.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

CONTENTS

PLATES

Vol. XXXVI. FEBRUARY, 1910. No. 2.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

A CONCRETE WATER TOWER.

By A. Kempkey, Jun. Am. Soc. C. E.

To be Presented March 16th, 1910.

The City of Victoria is situated on the southern end of Vancouver Island, in the Province of British Columbia, Canada, and is the capital of the Province.

In common with all cities of the extreme West, its growth has been very rapid within the last few years. The population of the city proper, together with that of the municipality of Oak Bay, immediately adjacent, is now about 35 000.

The Victoria water-works are owned by the city and operated under the direction of a Water Commissioner appointed by the City Council. By special agreement, water is supplied to Oak Bay in bulk, this municipality having its own distributing system.

The rapid increase in population, together with the fact that in recent years very little had been done toward increasing the water supply, resulted in the necessity for remodeling the entire system, and there are very few cities where this would involve as many complex problems or a greater variety of work.

Water is drawn from Elk Lake, situated about five miles north of the city; thence it flows by gravity to the pumping station about four miles distant, and from there is pumped directly to the consumers.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

The remodeling of the system, as recently completed, provided for:

1.—Increasing the capacity of Elk Lake by a system of levees.

2.—Increasing the capacity of the main to the pumping station by replacing about two miles of the old 16-in., wrought-iron, riveted pipe with 24-in. riveted steel pipe.

3.—Increasing the capacity of the pumping station by the installation of a 4 500 000-gal. pumping engine of the close-connected, cross-compound, Corliss, crank-and-fly-wheel type.

4.—The construction of a 20 000 000-gal. concrete-lined distributing reservoir in the city.

5.—The entire remodeling of the distributing system, necessitating the laying of about ½ mile each of 18-in. and 27-in. pipe, and about 1 mile of 24-in. riveted steel pipe; also about 3 000 tons of cast-iron pipe, varying in size from 4 to 12 in.

6.—The provision for a high-level service by means of an elevated tank of approximately 100 000 gal. capacity, water being supplied to the tank by two electric-driven triplex pumps, each having a capacity of 100 000 gal. per 24 hours, against a dynamic head of 150 ft., and arranged to start and stop automatically with a variation of 3 ft. in the elevation of the water in the tank. These pumps are located about one mile from the tower, and are controlled by a float-operated auto-start, in the base of the tower.

A description of the elevated tank, which is novel in design, with the reasons for adopting the type of structure used, the method of construction, and the detailed cost, form the basis of this paper.

The tower is on the top of the highest hill in the city, in the heart of the most exclusive residential district, beautiful homes clustering about its base. The necessity for architectural treatment of the structure is thus seen to be of prime importance. In fact, the opposition of the local residents to the ordinary type of elevated tank, that is, latticed columns supporting a tank with a hemispherical bottom and a conical roof, rendered its use impossible, although tenders were invited on such a structure.

It is believed that under the conditions of location, three types of structure should be considered: First, an all-steel structure, the ornamentation being produced by casing in with brick or concrete; second, a brick-and-steel, or a concrete-and-steel, structure, such as the one actually erected; third, a typical reinforced concrete structure.

Considering only that portion below the tank, the amount of material required to case in a structure of the first type would be substantially the same as that used to support the tank in a structure of the second type. Consequently, the steel substructure, for all practical purposes, would represent a dead loss, and, therefore, the economy of this type is open to serious question.

A tender was received for a reinforced concrete structure identical in outward appearance with the one built, but, owing to the natural conservatism of the local residents regarding this type of construction, it was not acceptable.

The tower, as built, consists of a hollow cylinder of plain concrete, 109 ft. high, and having an inside diameter of 22 ft. The walls are 10 in. thick for the first 70 ft. and 6 in. thick for the remaining 39 ft., and are ornamented with six pilasters (70 ft. high, 3 ft. wide, and 7 in. thick), a 4-ft. belt, then twelve pilasters (12 ft. high, 18 in. wide, and 7 in. thick), a cornice, and a parapet wall.

A steel tank of the ordinary type is embedded in the upper 40 ft. of this cylinder. To form the bottom of this tank, a plain concrete dome is thrown across the cylinder at a point about 70 ft. from the base, the thrust of this dome being taken up by two steel rings, $\frac{1}{2}$ in. by 14 in. and $\frac{3}{8}$ in. by 18 in., bedded into the walls of the tower, the latter ring being riveted to the lower course of the tank.

The tank is covered with a roof of reinforced concrete, 4 in. thick, conical in shape, and reinforced with $\frac{1}{2}$-in. twisted steel bars. The design of the structure is clearly shown in Fig. 1.

The tower is built on out-cropping, solid rock. This rock was roughly stepped, and a concrete sub-base built. This sub-base consists of a hollow ring, with an inside diameter of 20 ft., the walls being 5 ft. thick. It is about 2 ft. high on one side and 7 ft. high on the other, and forms a level base on which the tower is built. The forms for this sub-base consist of vertical lagging and circumferential ribs. The lagging is of double-dressed, 2 by 3-in. segments, and the ribs are of 2 by 12-in. segments, 6 ft. long, lapping past one another and securely spiked together to form complete or partial circles. These ribs are spaced 2 ft. center to center.

Similar construction was used to form the taper base of the tower proper, except, of course, that the radii of the segments forming the successive ribs decreased with the height of the rib. Tapered lagging

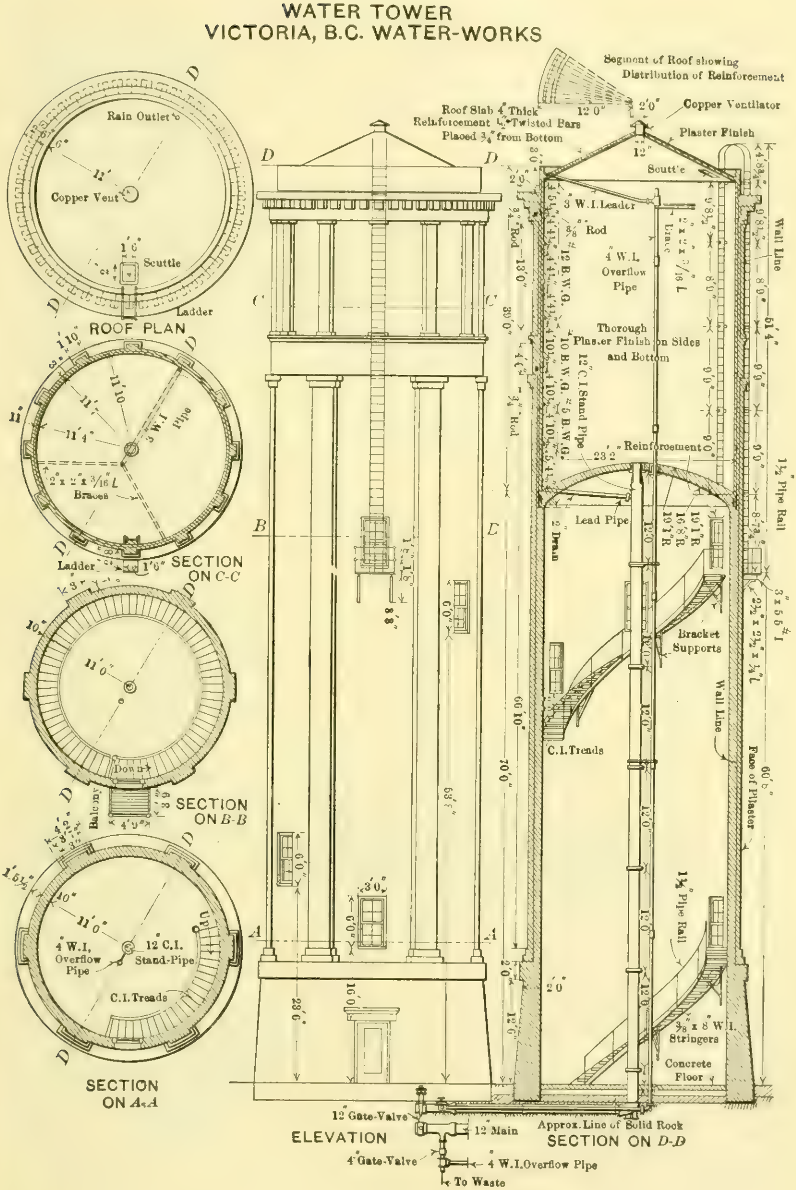
WATER TOWER
VICTORIA, B.C. WATER-WORKS
ROOF PLAN
SECTION ON C-C
SECTION ON B-B
SECTION ON A-A
ELEVATION
SECTION ON D-D
Segment of Roof showing Distribution of Reinforcement
Copper Ventilator
Plaster Finish
Roof Slab 4" Thick
Reinforcement ½" Twisted Bars Placed ¾" from Bottom
Scuttle
Rain Outlet
Copper Vent
Ladder
3 W.I. Leader
4" W.I. Overflow Pipe
Thorough Plaster Finish on Sides and Bottom
12" C.I. Stand Pipe
Reinforcement
Lead Pipe
2" Drain
Bracket Supports
Wall Line
C.I. Treads
Face of Pilaster
1¼" Pipe Rail
⅜" x 8" W.I. Stringers
Concrete Floor
Approx. Line of Solid Rock
12" Gate-Valve
12" Main
4" Gate-Valve
4" W.I. Overflow Pipe
To Waste
Balcony
12" C.I. Stand-Pipe
Braces

FIG. 1.

was used, being made by double dressing 2 by 6-in. pieces to $1\frac{3}{4}$ by $5\frac{13}{16}$ in., and ripping on a diagonal, thus making two staves, 3 in. wide at one end and $2\frac{3}{4}$ in. wide at the other. This tapered lagging was used again on the 4-ft. belt and cornice forms, the taper being turned alternately up and down.

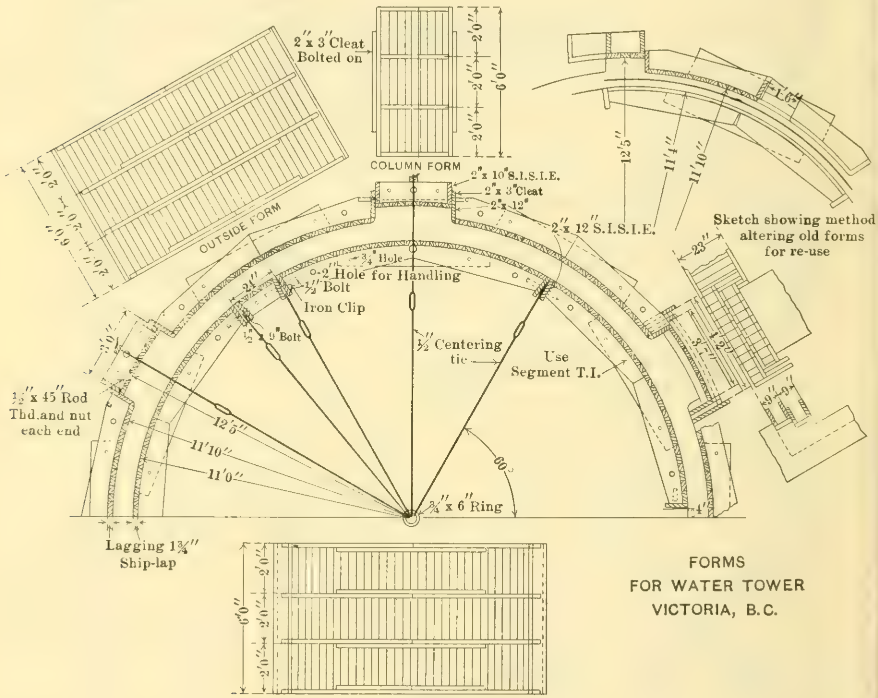

FIG. 2.

The interior diameter being uniform up to the bottom of the dome, collapsible forms were used from the beginning. These forms were constructed in six large sections, 6 ft. high, with one small key section with wedge piece to facilitate stripping, as shown in Fig. 2. There were three tiers of these, bolted end to end horizontally and to each other vertically.

Above the taper base and except in the 4-ft. belt and cornice, collapsible forms were used on the outside also. There were six sections extending from column to column and six column sections, all

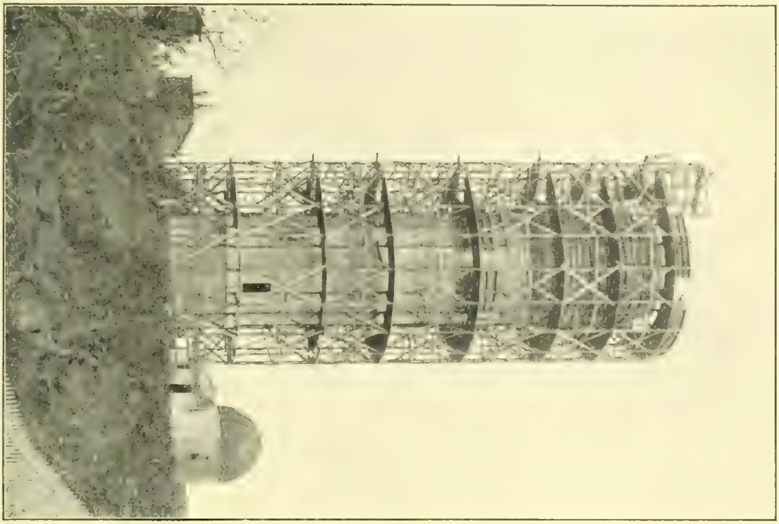

FIG. 1.—SCAFFOLDING FOR WATER TOWER.

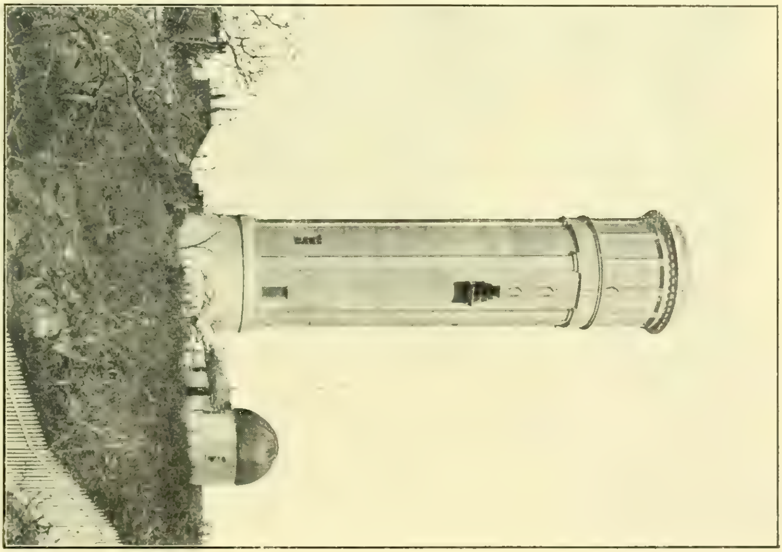

FIG. 2.—COMPLETED WATER TOWER.

bolted together circumferentially and constructed as shown in Fig. 2. Three tiers of these were also bolted together both vertically and horizontally.

Having filled the top tier, the mode of operation was as follows:

All horizontal bolts in the lower inside and outside forms were removed, as was also the small key section on the inside; this left each section suspended to the corresponding one immediately above it by the vertical bolts before mentioned. It is thus seen that in each case the center tier performed the double duty of holding the upper tier, which was full of green concrete, and the sections of the lower tier, until they were hoisted up and again placed in position to be filled.

These lower forms were then hoisted by hand—four-part tackles being used—and placed in position on the top forms, their bottom edges being carefully set flush with the top edge of the form already in position, and then bolted to it. On the outside, the column forms, and on the inside, the wedge and key sections were set last. A 3-lb. plumb-bob and a fine line were suspended from the inner scaffold and carefully centered over a point set in the rock at the base. This line was in the exact center of the tower, and the tops of all the forms, after each shift, were carefully set from it by measurement, thus keeping the structure plumb.

The first 23 in. of the barrel of the tower was moulded with special outside forms, constructed so as to form the bases of the large pilasters. After eleven applications of the 6-ft. forms, these 23-in. sections were reversed to form the capitals, thus making these pilasters, 69 ft. 10 in. over all.

The forms of the 4-ft. belt and beading were made in twelve sections of simple segments and vertical lagging, as shown in Fig. 2.

Two sets of the outside forms were split longitudinally, as shown in Fig. 2, and used to form the small pilasters. The first set was put in place, filled, and the concrete allowed to harden. The bolts were loosened and the forms raised 5½ in. vertically, again bolted up, and the second set was placed in position, bringing the top of the second set up to the bottom of the cornice. The bases and capitals of the small pilasters were moulded on afterward.

The cornice forms are clearly shown in Fig. 2. The small boxes separating the dentils are made of light stuff, and tacked into the

cornice forms so that, in stripping, they would remain in place and could be taken out separately, in order to prevent the breaking off of the corners of the dentils. A number of outside and inside sections were sawed in half horizontally in order to provide forms for the parapet wall.

The inside diameter of the tank is 8 in. greater than the inside diameter of the base. Two sets of inside forms were split longitudinally and opened out as shown in Fig. 2, and another small section was added to complete the circle. The remaining set was left in place to support the dome forms.

The dome forms were made in twelve sections, bolted together to facilitate stripping. All ribs and segments were cut to size on the ground, put together in place, and then covered with lagging and two-ply tar paper. The lagging on the lower sharp curve was formed of a double thickness of $\frac{3}{8}$-in. spruce, the remainder being 1 by 4-in. pine, sized to a uniform thickness of $\frac{7}{8}$ in. Fig. 3 shows the construction of these forms and the method of putting on the lagging.

The roof forms were made in eight sections and bolted together to facilitate stripping. All ribs and segments were cut to size on the ground, put together in place, and covered with 1 by 4-in. lagging, dressed to a uniform thickness of $\frac{7}{8}$ in., and two-ply tar paper. Fig. 3 shows the construction of these forms. The segments being put in horizontally instead of square with the lagging, gave circles instead of parabolas, making them much easier to lay out, and giving a form which was amply stiff.

The question of using an inside scaffold only was carefully considered, but owing to the considerable amount of ornamentation on the outside, necessitating a large number of individual forms, it was not thought that any economy would result.

Fig. 4 and Figs. 1 and 2, Plate XXXIII, show clearly the construction of the scaffolding.

All concrete was mixed wet, in a motor-driven, Smith mixer, and handled off the outside scaffold, being sent up in wheel-barrows on the ordinary contractor's hoist and placed in the forms through an iron chute having a hopper mouth. This chute was built in three sections bolted together, either one, two, or three sections being used, depending on the distance of the forms below the deck. When the top of the forms reached the elevation of any deck, the concrete was put

in through the chute from the deck above. The chute was light and easily shifted by the wheel-barrow men, assisted by the man placing the concrete, during the interval between successive wheel-barrows.

The concrete, except that for the roof and parapet, was composed of sand and broken rock, the run of the crusher being used. That for the roof and parapet was composed of sand and gravel. The only reason for using gravel for the concrete of the roof was the ease with

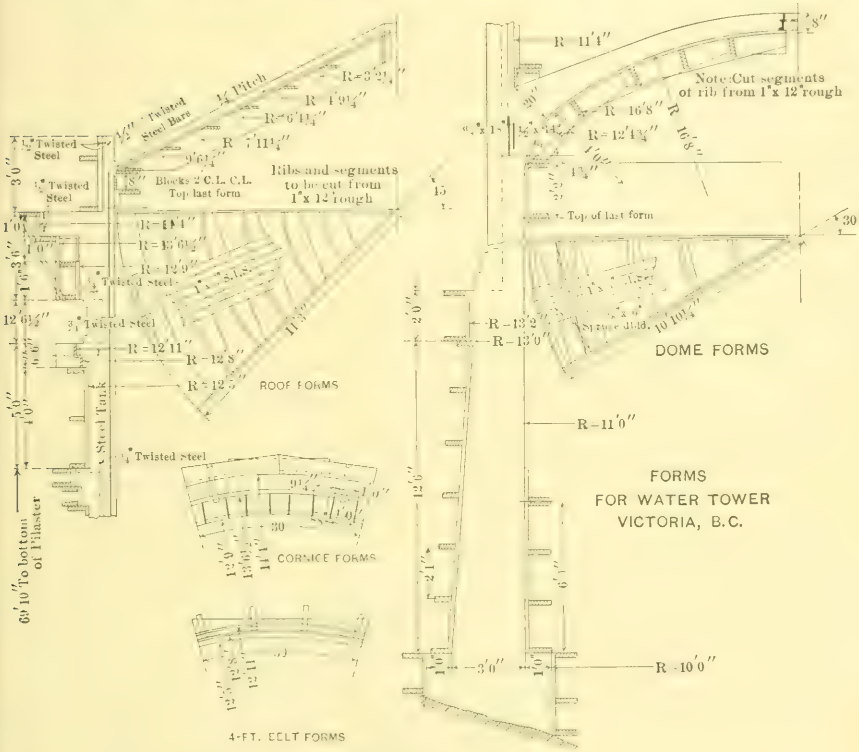

FIG. 3.

which it could be obtained in small quantities, the supply of broken rock having been used up, and this being the last concrete work to be done.

The concrete used was as follows: 1:3:6 for the sub-base and taper base; 1:3:5 for the barrel of the tower and tank casing; and 1:2:4 for the dome and roof. The dome was put in at one time, there being no joint, the same being true of the roof. Vancouver Portland cement,

manufactured on the island about 15 miles from the city, was used throughout the work.

Before filling, the inside of the tank was given a plaster coat, consisting of 1 part cement to $1\frac{3}{4}$ parts of fine sand. This proved to be insufficient to prevent leakage, the water seeping through the dome and appearing on the outside of the structure along the line of the bottom of the rings. Three more coats were then applied over the entire tank, and two additional ones over the dome and about 8 ft. up on the sides, and except for one or two small spots which show just a sign of moisture, the tank is perfectly tight.

The barrel of the tower was carried up to a height of 66 ft. A special set of inside forms, about 2 ft. high, extending to the springing line of the dome, was then put in, and the dome forms were set up on it. The idea was that this 2-ft. form could be knocked out piece by piece and the weight of the dome form taken on wedges to the last 6-ft. form, these wedges being gradually slackened down in order to allow the dome form to settle clear of the dome. As a matter of fact, this was done, but the dome forms, being very tight, did not settle, and had to be pried off a section at a time. A similar method was used for slacking down the roof forms, with similar results.

After the dome forms had been put in, the concrete was carried up approximately to the elevation of the bottom of the rings. Small neat cement pads were then put in and accurately leveled, and on these the steel rings were placed, and the steel tank was erected.

In order to insure a perfectly round tank, each course was erected against wooden templates accurately centered and fastened to the inside scaffold. The tank is the ordinary type of light steel, the lower course being $\frac{3}{16}$-in., the next, No. 8 B. W. gauge, the next, No. 10 B. W. gauge, and the remaining four, No. 12 B. W. gauge.

Work on the foundation was started on August 15th, 1908, and the tower was not completed until April 1st, 1909. Much time was lost waiting for the delivery of the steel, and also owing to a period of very cold weather which caused entire cessation of work for about one month.

The tower as completed presents a striking appearance. In order to obliterate rings due to the successive application of the forms and to cover the efflorescence so common to concrete structures, the outside was given two coats of neat cement wash applied with ordinary kalso-

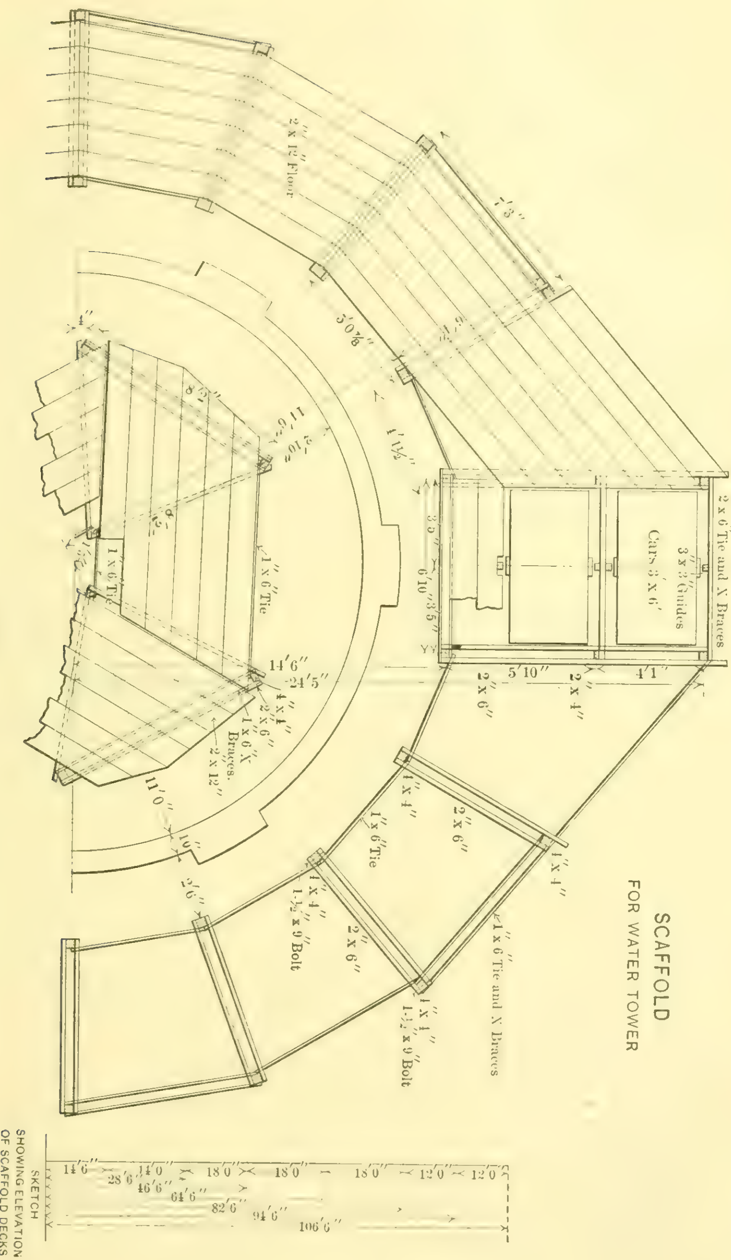
SCAFFOLD
FOR WATER TOWER
SKETCH
SHOWING ELEVATION
OF SCAFFOLD DECKS
2 x 12" Floor
1 x 6" Tie
3 x 3" Guides
Cars 3' x 6'
2 x 6" Tie and X Braces
1 x 6" Tie and X Braces
1-1/2 x 9" Bolt
1 x 6" X Braces.

Fig. 4.

mining brushes, and, up to the present time, this seems to have been very effective in accomplishing the desired result.

Irregularities due to forms are unnoticeable at a distance of 200 or 300 ft., and the grouting gave a very uniform color.

The application of two coats of cement wash cost, for labor, $97.68, and for material, $15.18, or $1.32 per 100 sq. ft., labor being at the rate of $2.25 per 8 hours and cement costing $2.53 per bbl. delivered on the work.

The tower was designed by Arthur L. Adams, M. Am. Soc. C. E., under whose direction the plans for all the work of remodeling the water-works system were prepared and executed. The forms, scaffolding, etc., were designed by the writer, who was also in immediate charge of the erection.

Tenders received for the construction of the tower covered an extremely wide range, and indicated at once the utter lack of knowledge on the part of the bidders of the cost of a structure of this kind. Inasmuch as none of them had had previous experience in this class of construction, the engineer deemed it the part of wisdom and economy to retain the construction under his immediate supervision, and, therefore, the work was done by days' labor.

Table 1 gives the cost of the structure. The total herein given will not coincide with the total cost as shown by the city's books, for the reason that various items not properly chargeable to the structure itself have been omitted, the principal ones of which are the cost of the site, the laying of about 600 ft. of sewer pipe to connect with the overflow, and considerable expense incident to the construction of a wagon road to the tower.

The rates of wages paid, all being on a basis of an 8-hour day, were as follows:

Common labor	$2.25 and $2.50
Carpenter	4.00
Carpenter's helper	2.75
Boiler-maker	3.50
Holders on	2.50
Boiler-maker foreman	5.00
Plasterers	6.00
Plasterers' helpers	3.00

The cost of material was as follows:

Cement, per barrel	$2.53
Sand, per yard	1.47
Rock, per yard	0.80
Lumber, per 1 000 ft. B. M.	14.00 and 16.00

All these prices are for material delivered on the work.

An examination of the cost data, as given, will show that for the most part the unit costs are very high. This is due chiefly to the continued interruption of the work, during its later stages, owing to bad weather, particularly in the case of the erection of the steel tank. The material cost in this case was also exceedingly high.

In the case of the concreting, inability to purchase a hoist and motor and the high cost of renting the same, together with the delays mentioned, added greatly to the unit cost.

When it is considered that the cost of plastering covers that of four coats over the entire inside of the tank and three more over about one-third of it, it does not appear so high, especially in view of the high rate of wages paid.

The cost per yard for concrete alone was $25.126, and this is probably about 25% in excess of the cost of the same class of work executed under more favorable conditions as to location, weather conditions, etc.

TABLE 1.—COST OF HIGH-LEVEL TOWER, VICTORIA WATER-WORKS.
(412 cu. yd.)

	Total Cost.			Unit Cost.	
	Rate per hour.	Amount.	Complete.	Labor.	Material.
Preliminary Work:					
Labor, Carpenter	$0.50	$11.00			
Labor	0.344	64.94			
"	0.281	249.67	$325.61	$0.790	
Material		133.62	133.62		$0.324
Forms:					
Building, shifting, and stripping:					
Labor, Carpenter	0.50	1 832.99			
Labor	0.344	80.85			
"	0.281	563.84	2 477.68	6.014	
Material:					
Lumber		583.49			
Hardware		325.51			
Miscellaneous		13.90	922.90		2.240
Scaffold:					
Erecting and tearing down:					
Labor, Carpenter	0.50	693.00			
Labor	0.344	350.59			
"	0.281	117.27	1 160.86	2.818	
Material:					
Lumber		487.77			
Hardware		202.79	690.56		1.676
Concreting:					
Labor	0.50	142.00			
"	0.344	11.00			
"	0.281	947.81	1 100.81	2.672	
Material:					
Rock		317.30			
Sand		335.72			
Cement		1 591.97			
Motor and Hoist:					
Rental		406.56			
Power		83.53	2 735.08		6.638
Plastering (3 000 sq. ft.):					
Labor, Plasterers	0.75	116.50			
Labor	0.46⅞	15.00			
"	0.37½	198.52			
"	0.281	105.66	435.68	14.52 per sq. ft.	
Material:					
Sand		8.64			
Cement		66.10			
Alum and Potash		16.00	90.74	3.25 per sq. ft.	
Cement Wash (8 560 sq. ft.):					
Labor	0.43¾	50.00			
"	0.281	47.68	97.68	1.14 per 100 sq. ft	
Material:					
Cement		15.18	15.18	0.18 " " " "	
Windows, doors, and scuttle:					
Labor	0.50	49.00	49.00		
Material:					
1 door, 7 windows, etc.		47.26	47.26		
Equipment:					
40% of $461.46		184.58	184.58	0.448	
Superintendence			1 241.45	1.506	

TABLE 1.—(*Continued.*)

	Total Cost.			Unit Cost.	
	Rate per hour.	Amount.	Complete.	Labor.	Material.
Steel Tank :					
Labor, Carpenter	$0.50	$124.24	....	....	....
Helper	0.344	2.75	....	....	....
Boiler-makers	....	382.57	....	....	....
Holders on	....	147.33	....	....	....
Labor	....	40.61	....	....	....
Foreman	0.625	186.25	$883.75	$0.0441 per lb.	....
Material :					
Tank, rivets, etc. (20 000 lb.)	....	....	1 740.69	....	0.0875
Iron-work :					
Spiral stairway, inlet, and overflow pipes, ventilator, reinforcing steel, etc.:					
Labor, Machinists	0.50	89.50	....	....	....
Helper	0.344	240.16	....	....	....
Labor	0.281	100.79	430.45	....	....
Material	....	1 814.71	1 814.71	....	....
Total	....	....	$16 578.29	....	....

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PAPERS AND DISCUSSIONS

SOME MOOTED QUESTIONS IN REINFORCED CONCRETE DESIGN.

By Edward Godfrey, M. Am. Soc. C. E.
To be Presented March 16th, 1910.

Not many years ago physicians had certain rules and practices by which they were guided as to when and where to bleed a patient in order to relieve or cure him. What of those rules and practices to-day? If they were logical, why have they been abandoned?

It is the purpose of this paper to show that reinforced concrete engineers have certain rules and practices which are no more logical than those governing the blood-letting of former days. If the writer fails in this, by reason of the more weighty arguments on the other side of the questions he propounds, he will at least have brought out good reasons which will stand the test of logic for the rules and practices which he proposes to condemn, and which, at the present time, are quite lacking in the voluminous literature on this comparatively new subject.

Destructive criticism has recently been decried in an editorial in an engineering journal. Some kinds of destructive criticism are of the highest benefit; when it succeeds in destroying error, it is reconstructive. No reform was ever accomplished without it, and no reformer ever existed who was not a destructive critic. If showing

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

up errors and faults is destructive criticism, we cannot have too much of it; in fact, we cannot advance without it. If engineering practice is to be purged of its inconsistencies and absurdities, it will never be done by dwelling on its excellencies.

Reinforced concrete engineering has fairly leaped into prominence and apparently into full growth, but it still wears some of its swaddling-bands. Some of the garments which it borrowed from sister forms of construction in its short infancy still cling to it, and, while these were, perhaps, the best makeshifts under the circumstances, they fit badly and should be discarded. It is some of these misfits and absurdities which the writer would like to bring prominently before the Engineering Profession.

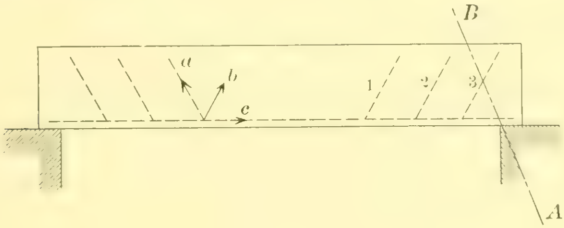

FIG. 1.

The first point to which attention is called, is illustrated in Fig. 1. It concerns sharp bends in reinforcing rods in concrete. Fig. 1 shows a reinforced concrete design, one held out, in nearly all books on the subject, as a model. The reinforcing rod is bent up at a sharp angle, and then may or may not be bent again and run parallel with the top of the beam. At the bend is a condition which resembles that of a hog-chain or truss-rod around a queen-post. The reinforcing rod is the hog-chain or the truss-rod. Where is the queen-post? Suppose this rod has a section of 1 sq. in. and an inclination of 60° with the horizontal, and that its unit stress is 16 000 lb. per sq. in. The forces, *a* and *b*, are then 16 000 lb. The force, *c*, must be also 16 000 lb. What is to take this force, *c*, of 16 000 lb.? There is nothing but concrete. At 500 lb. per sq. in., this force would require an area of 32 sq. in. Will some advocate of this type of design please state where this area can be found? It must, of necessity, be in contact with the rod, and, for structural reasons, because of the lack of stiffness in the rod, it would have to be close to the point of bend. If analogy to the queen-

post fails so completely, because of the almost complete absence of the post, why should not this borrowed garment be discarded?

If this same rod be given a gentle curve of a radius twenty or thirty times the diameter of the rod, the side unit pressure will be from one-twentieth to one-thirtieth of the unit stress on the steel. This being the case, and being a simple principle of mechanics which ought to be thoroughly understood, it is astounding that engineers should perpetrate the gross error of making a sharp bend in a reinforcing rod under stress.

The second point to which attention is called may also be illustrated by Fig. 1. The rod marked 3 is also like the truss-rod of a queen-post truss in appearance, because it ends over the support and has the same shape. But the analogy ends with appearance, for the function of a truss-rod in a queen-post truss is not performed by such a reinforcing rod in concrete, for other reasons than the absence of a post. The truss-rod receives its stress by a suitable connection at the end of the rod and over the support of the beam. The reinforcing rod, in this standard beam, ends abruptly at the very point where it is due to receive an important element of strength, an element which would add enormously to the strength and safety of many a beam, if it could be introduced.

Of course a reinforcing rod in a concrete beam receives its stress by increments imparted by the grip of the concrete; but these increments can only be imparted where the tendency of the concrete is to stretch. This tendency is greatest near the bottom of the beam, and when the rod is bent up to the top of the beam, it is taken out of the region where the concrete has the greatest tendency to stretch. The function of this rod, as reinforcement of the bottom flange of the beam, is interfered with by bending it up in this manner, as the beam is left without bottom-flange reinforcement, as far as that rod is concerned, from the point of bend to the support.

It is true that there is a shear or a diagonal tension in the beam, and the diagonal portion of the rod is apparently in a position to take this tension. This is just such a force as the truss-rod in a queen-post truss must take. Is this reinforcing rod equipped to perform this office? The beam is apt to fail in the line, A B. In fact, it is apt to crack from shrinkage on this or almost any other line, and to leave the strength dependent on the reinforcing steel. Suppose such a crack

should occur. The entire strength of the beam would be dependent on the grip of the short end of Rod 3 to the right of the line, *A B*. The grip of this short piece of rod is so small and precarious, considering the important duty it has to perform, that it is astounding that designers, having any care for the permanence of their structures, should consider for an instant such features of design, much less incorporate them in a building in which life and property depend on them.

The third point to which attention is called, is the feature of design just mentioned in connection with the bent-up rod. It concerns the anchorage of rods by the embedment of a few inches of their length in concrete. This most flagrant violation of common sense has its most conspicuous example in large engineering works, where of all places better judgment should prevail. Many retaining walls have been built, and described in engineering journals, in papers before engineering societies of the highest order, and in books enjoying the greatest reputation, which have, as an essential feature, a great number of rods which cannot possibly develop their strength, and might as well be of much smaller dimensions. These rods are the vertical and horizontal rods in the counterfort of the retaining wall shown at *a*, in Fig. 2. This retaining wall consists of a front curtain wall and a horizontal slab joined at intervals by ribs or counterforts. The manifest and only function of the rib or counterfort is to tie together the curtain wall and the horizontal slab. That it is or should be of concrete is because the steel rods which it contains, need protection. It is clear that failure of the retaining wall could occur by rupture through the Section *A B*, or through *B C*. It is also clear that, apart from the cracking of the concrete of the rib, the only thing which would produce this rupture is the pulling out of the short ends of these reinforcing rods. Writers treat the triangle, *A B C*, as a beam, but there is absolutely no analogy between this triangle and a beam. Designers seem to think that these rods take the place of so-called shear rods in a beam, and that the inclined rods are equivalent to the rods in a tension flange of a beam. It is hard to understand by what process of reasoning such results can be attained. Any clear analysis leading to these conclusions would certainly be a valuable contribution to the literature on the subject. It is scarcely possible, however, that such analysis will be brought forward, for it is the apparent policy of

the reinforced concrete analyist to jump into the middle of his proposition without the encumbrance of a premise.

There is positively no evading the fact that this wall could fail, as stated, by rupture along either $A\ B$ or $B\ C$. It can be stated just as positively that a set of rods running from the front wall to the horizontal slab, and anchored into each in such a manner as would be adopted were these slabs suspended on the rods, is the only rational and the only efficient design possible. This design is illustrated at b in Fig. 2.

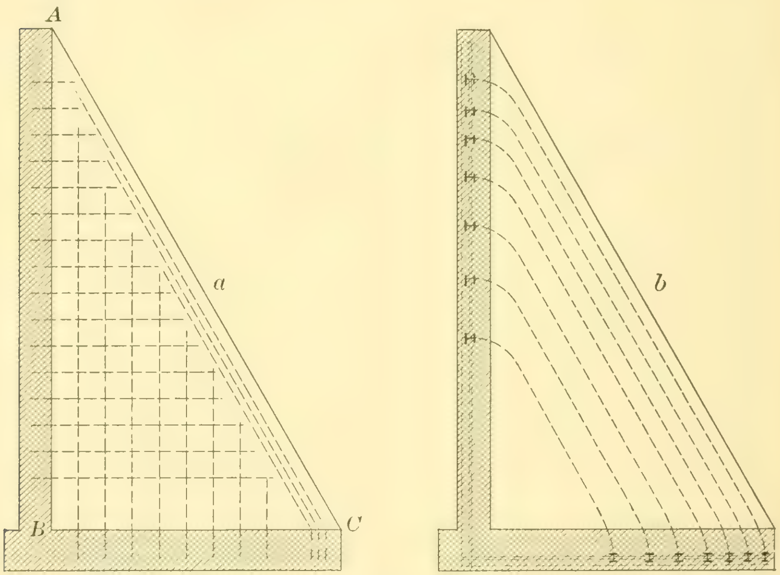

FIG. 2.

The fourth point concerns shear in steel rods embedded in concrete. For decades, specifications for steel bridges have gravely given a unit shear to be allowed on bridge pins, and every bridge engineer knows or ought to know that, if a bridge pin is properly proportioned for bending and bearing, there is no possibility of its being weak from shear. The centers of bearings cannot be brought close enough together to reduce the size of the pin to where its shear need be considered, because of the width required for bearing on the parts. Concrete is about one-thirtieth as strong as steel in bearing. There is, therefore, somewhat less than one-thirtieth of a reason for specifying any shear on steel rods embedded in concrete.

The gravity of the situation is not so much the serious manner in which this unit of shear in steel is written in specifications and building codes for reinforced concrete work (it does not mean anything in specifications for steelwork, because it is ignored), but it is apparent when designers soberly use these absurd units, and proportion shear rods accordingly.

Many designers actually proportion shear rods for shear, shear in the steel at units of 10 000 or 12 000 lb. per sq. in.; and the blame for this dangerous practice can be laid directly to the literature on reinforced concrete. Shear rods are given as standard features in the design of reinforced concrete beams. In the Joint Report of the Committee of the various engineering societies, a method for proportioning shear members is given. The stress, or shear per shear member, is the longitudinal shear which would occur in the space from member to member. No hint is given as to whether these bars are in shear or tension; in fact, either would be absurd and impossible without greatly overstressing some other part. This is just a sample of the state of the literature on this important subject. Shear bars will be taken up more fully in subsequent paragraphs.

The fifth point concerns vertical stirrups in a beam. These stirrups are conspicuous features in the designs of reinforcing concrete beams. Explanations of how they act are conspicuous in the literature on reinforced concrete by its total absence. By stirrups are meant the so-called shear rods strung along a reinforcing rod. They are usually U-shaped and looped around the rod.

It is a common practice to count these stirrups in the shear, taking the horizontal shear in a beam. In a plate girder, the rivets connecting the flange to the web take the horizontal shear or the increment to the flange stress. Compare two $\frac{3}{4}$-in. rivets tightly driven into holes in a steel angle, with a loose vertical rod, $\frac{3}{4}$ in. in diameter, looped around a reinforcing rod in a concrete beam, and a correct comparison of methods of design in steel and reinforced concrete, as they are commonly practiced, is obtained.

These stirrups can take but little hold on the reinforcing rods—and this must be through the medium of the concrete—and they can take but little shear. Some writers, however, hold the opinion that the stirrups are in tension and not in shear, and some are bold enough to compare them with the vertical tension members of a Howe truss.

Imagine a Howe truss with the vertical tension members looped around the bottom chord and run up to the top chord without any connection, or hooked over the top chord; then compare such a truss with one in which the end of the rod is upset and receives a nut and large washer bearing solidly against the chord. This gives a comparison of methods of design in wood and reinforced concrete, as they are commonly practiced.

Anchorage or grip in the concrete is all that can be counted on, in any event, to take up the tension of these stirrups, but it requires an embedment of from 30 to 50 diameters of a rod to develop its full strength. Take 30 to 50 diameters from the floating end of these shear members, and, in some cases, nothing or less than nothing will be left. In any case the point at which the shear member, or stirrup, is good for its full value, is far short of the centroid of compression of the beam, where it should be; in most cases it will be nearer the bottom of the beam. In a Howe truss, the vertical tension members having their end connections near the bottom chord, would be equivalent to these shear members.

The sixth point concerns the division of stress into shear members. Briefly stated, the common method is to assume each shear member as taking the horizontal shear occurring in the space from member to member. As already stated, this is absurd. If stirrups could take shear, this method would give the shear per stirrup, but even advocates of this method acknowledge that they can not. To apply the common analogy of a truss: each shear member would represent a tension web member in the truss, and each would have to take all the shear occurring in a section through it.

If, for example, shear members were spaced half the depth of a beam apart, each would take half the shear by the common method. If shear members take vertical shear, or if they take tension, what is between the two members to take the other half of the shear? There is nothing in the beam but concrete and the tension rod between the two shear members. If the concrete can take the shear, why use steel members? It is not conceivable that an engineer should seriously consider a tension rod in a reinforced concrete beam as carrying the shear from stirrup to stirrup.

The logical deduction from the proposition that shear rods take tension is that the tension rods must take shear, and that they must

take the full shear of the beam, and not only a part of it. For these shear rods are looped around or attached to the tension rods, and since tension in the shear rods would logically be imparted through the medium of this attachment, there is no escaping the conclusion that a large vertical force (the shear of the beam) must pass through the tension rod. If the shear member really relieves the concrete of the shear, it must take it all. If, as would be allowable, the shear rods take but a part of the shear, leaving the concrete to take the remainder, that carried by the rods should not be divided again, as is recommended by the common method.

Bulletin No. 29 of the University of Illinois Experiment Station shows by numerous experiments, and reiterates again and again, that shear rods do not act until the beam has cracked and partly failed. This being the case, a shear rod is an illogical element of design. Any element of a structure, which cannot act until failure has started, is not a proper element of design. In a steel structure a bent plate which would straighten out under a small stress and then resist final rupture, would be a menace to the rigidity and stability of the structure. This is exactly analogous to shear rods which cannot act until failure has begun.

When the man who tears down by criticism fails to point out the way to build up, he is a destructive critic. If, under the circumstances, designing with shear rods had the virtue of being the best thing to do with the steel and concrete disposed in a beam, as far as experience and logic in their present state could decide, nothing would be gained by simply criticising this method of design. But logic and tests have shown a far simpler, more effective, and more economical means of disposing of the steel in a reinforced concrete beam.

In shallow beams there is little need of provision for taking shear by any other means than the concrete itself. The writer has seen a reinforced slab support a very heavy load by simple friction, for the slab was cracked close to the supports. In slabs, shear is seldom provided for in the steel reinforcement. It is only when beams begin to have a depth approximating one-tenth of the span that the shear in the concrete becomes excessive and provision is necessary in the steel reinforcement. Years ago, the writer recommended that, in such beams, some of the rods be curved up toward the ends of the span and anchored over the support. Such reinforcement completely

relieves the concrete of all shearing stress, for the stress in the rod will have a vertical component equal to the shear. The concrete will rest in the rod as a saddle, and the rod will be like the cable of a suspension span. The concrete could be in separate blocks with vertical joints, and still the load would be carried safely.

By end anchorage is not meant an inch or two of embedment in concrete, for an iron vise would not hold a rod for its full value by such means. Neither does it mean a hook on the end of the rod. A threaded end with a bearing washer, and a nut and a lock-nut to hold the washer in place, is about the only effective means, and it is simple and cheap. Nothing is as good for this purpose as plain round rods, for no other shape affords the same simple and effective means of end connection. In a line of beams, end to end, the rods may be extended into the next beam, and there act to take the top-flange tension, while at the same time finding anchorage for the principal beam stress.

The simplicity of this design is shown still further by the absence of a large number of little pieces in a beam box, as these must be held in their proper places, and as they interfere with the pouring of the concrete.

It is surprising that this simple and unpatented method of design has not met with more favor and has scarcely been used, even in tests. Some time ago the writer was asked by the head of an engineering department of a college, for some ideas for the students to work up for theses, and suggested that they test beams of this sort. He was met by the astounding and fatuous reply that such would not be reinforced concrete beams. They would certainly be concrete beams, and just as certainly be reinforced.

Bulletin 29 of the University of Illinois Experiment Station contains a record of tests of reinforced concrete beams of this sort. They failed by the crushing of the concrete or by failure in the steel rods, and nearly all the cracks were in the middle third of the beams, whereas beams rich in shear rods cracked principally in the end thirds, that is, in the neighborhood of the shear rods. The former failures are ideal, and are easier to provide against. A crack in a beam near the middle of the span is of little consequence, whereas one near the support is a menace to safety.

The seventh point of common practice to which attention is called, is the manner in which bending moments in so-called continuous beams

are juggled to reduce them to what the designer would like to have them. This has come to be almost a matter of taste, and is done with as much precision or reason as geologists guess at the age of a fossil in millions of years.

If a line of continuous beams be loaded uniformly, the maximum moments are negative and are over the supports. Who ever heard of a line of beams in which the reinforcement over the supports was double that at mid-spans? The end support of such a line of beams cannot be said to be fixed, but is simply supported, hence the end beam would have a negative bending moment over next to the last support equal to that of a simple span. Who ever heard of a beam being reinforced for this? The common practice is to make a reduction in the bending moment, at the middle of the span, to about that of a line of continuous beams, regardless of the fact that they may not be continuous or even contiguous, and in spite of the fact that the loading of only one gives quite different results, and may give results approaching those of a simple beam.

If the beams be designed as simple beams—taking the clear distance between supports as the span and not the centers of bearings or the centers of supports—and if a reasonable top reinforcement be used over these supports to prevent cracks, every requirement of good engineering is met. Under extreme conditions such construction might be heavily stressed in the steel over the supports. It might even be overstressed in this steel, but what could happen? Not failure, for the beams are capable of carrying their load individually, and even if the rods over the supports were severed—a thing impossible because they cannot stretch out sufficiently—the beams would stand.

Continuous beam calculations have no place whatever in designing stringers of a steel bridge, though the end connections will often take a very large moment, and, if calculated as continuous, will be found to be strained to a very much larger moment. Who ever heard of a failure because of continuous beam action in the stringers of a bridge? Why cannot reinforced concrete engineering be placed on the same sound footing as structural steel engineering?

The eighth point concerns the spacing of rods in a reinforced concrete beam. It is common to see rods bunched in the bottom of such a beam with no regard whatever for the ability of the concrete to grip the steel, or to carry the horizontal shear incident to their stress, to

the upper part of the beam. As an illustration of the logic and analysis applied in discussing the subject of reinforced concrete, one well-known authority, on the premise that the unit of adhesion to rod and of shear are equal, derives a rule for the spacing of rods. His reasoning is so false, and his rule is so far from being correct, that two-thirds would have to be added to the width of beam in order to make it correct. An error of 66% may seem trifling to some minds, where reinforced concrete is considered, but errors of one-tenth this amount in steel design would be cause for serious concern. It is reasoning of the most elementary kind, which shows that if shear and adhesion are equal, the width of a reinforced concrete beam should be equal to the sum of the peripheries of all reinforcing rods gripped by the concrete. The width of the beam is the measure of the shearing area above the rods, taking the horizontal shear to the top of the beam, and the peripheries of the rods are the measure of the gripping or adhesion area.

Analysis which examines a beam to determine whether or not there is sufficient concrete to grip the steel and to carry the shear, is about at the vanishing point in nearly all books on the subject. Such misleading analysis as that just cited is worse than nothing.

The ninth point concerns the T-beam. Excessively elaborate formulas are worked out for the T-beam, and haphazard guesses are made as to how much of the floor slab may be considered in the compression flange. If a fraction of this mental energy were directed toward a logical analysis of the shear and gripping value of the stem of the T-beam, it would be found that, when the stem is given its proper width, little, if any, of the floor slab will have to be counted in the compression flange, for the width of concrete which will grip the rods properly will take the compression incident to their stress.

The tenth point concerns elaborate theories and formulas for beams and slabs. Formulas are commonly given with 25 or 30 constants and variables to be estimated and guessed at, and are based on assumptions which are inaccurate and untrue. One of these assumptions is that the concrete is initially unstressed. This is quite out of reason, for the shrinkage of the concrete on hardening puts stress in both concrete and steel. One of the coefficients of the formulas is that of the elasticity of the concrete. No more variable property of concrete is known than its coefficient of elasticity, which may vary from 1 000 000

to 5 000 000 or 6 000 000; it varies with the intensity of stress, with the kind of aggregate used, with the amount of water used in mixing, and with the atmospheric condition during setting. The unknown coefficient of elasticity of concrete and the non-existent condition of no initial stress, vitiate entirely formulas supported by these two props.

Here again destructive criticism would be vicious if these mathematical gymnasts were giving the best or only solution which present knowledge could produce, or if the critic did not point out a substitute. The substitute is so simple of application, in such agreement with experiments, and so logical in its derivation, that it is surprising that it has not been generally adopted. The neutral axis of reinforced concrete beams under safe loads is near the middle of the depth of the beams. If, in all cases, it be taken at the middle of the depth of the concrete beam, and if variation of intensity of stress in the concrete be taken as uniform from this neutral axis up, the formula for the resisting moment of a reinforced concrete beam becomes extremely simple and no more complex than that for a rectangular wooden beam.

The eleventh point concerns complex formulas for chimneys. It is a simple matter to find the tensile stress in that part of a plain concrete chimney between two radii on the windward side. If in this space there is inserted a rod which is capable of taking that tension at a proper unit, the safety of the chimney is assured, as far as that tensile stress is concerned. Why should frightfully complex formulas be proposed, which bring in the unknowable modulus of elasticity of concrete and can only be solved by stages or dependence on the calculations of some one else?

The twelfth point concerns deflection calculations. As is well known, deflection does not play much of a part in the design of beams. Sometimes, however, the passing requirement of a certain floor construction is the amount of deflection under a given load. Professor Gaetano Lanza has given some data on recorded deflections of reinforced concrete beams.* He has also worked out the theoretical deflections on various assumptions. An attempt to reconcile the observed deflections with one of several methods of calculating stresses led him to the conclusion that:

"The observations made thus far are not sufficient to furnish the means for determining the actual distribution of the stresses, and

* "Stresses in Reinforced Concrete Beams," *Journal*, Am. Soc. Mech. Engrs., Mid-October, 1909.

hence for the deduction of reliable formulæ for the computation of the direct stresses, shearing stresses, diagonal stresses, deflections, position of the neutral axis, etc., under a given load."

Professor Lanza might have gone further and said that the observations made thus far are sufficient to show the hopelessness of deriving a formula that will predict accurately the deflection of a reinforced concrete beam. The wide variation shown by two beam tests cited by him, in which the beams were identical, is, in itself, proof of this.

Taking the data of these tests, and working out the modulus of elasticity from the recorded deflections, as though the beams were of plain concrete, values are found for this modulus which are not out of agreement with the value of that variable modulus as determined by other means. Therefore, if the beams be considered as plain concrete beams, and an average value be assumed for the modulus or coefficient of elasticity, a deflection may be found by a simple calculation which is an average of that which may be expected. Here again, simple theory is better than complex, because of the ease with which it may be applied, and because it gives results which are just as reliable.

The thirteenth point concerns the elastic theory as applied to a reinforced concrete arch. This theory treats a reinforced concrete arch as a spring. In order to justify its use, the arch or spring is considered as having fixed ends. The results obtained by the intricate methods of the elastic theory and the simple method of the equilibrium polygon, are too nearly identical to justify the former when the arch is taken as hinged at the ends.

The assumption of fixed ends in an arch is a most extravagant one, because it means that the abutments must be rigid, that is, capable of taking bending moments. Rigidity in an abutment is only effected by a large increase in bulk, whereas strength in an arch ring is greatly augmented by the addition of a few inches to its thickness. By the elastic theory, the arch ring does not appear to need as much strength as by the other method, but additional stability is needed in the abutments in order to take the bending moments. This latter feature is not dwelt on by the elastic theorists.

In the ordinary arch, the criterion by which the size of abutment is gauged, is the location of the line of pressure. It is difficult and

expensive to obtain depth enough in the base of the abutment to keep this line within the middle third, when only the thrust of the arch is considered. If, an addition to the thrust, there is a bending moment which, for many conditions of loading, further displaces the line of pressure toward the critical edge, the difficulty and expense are increased. It cannot be gainsaid that a few cubic yards of concrete added to the ring of an arch will go much further toward strengthening the arch than the same amount of concrete added to the two abutments.

In reinforced concrete there are ample grounds for the contention that the carrying out of a nice theory, based on nice assumptions and the exact determination of ideal stresses, is of far less importance than the building of a structure which is, in every way, capable of performing its function. There are more than ample grounds for the contention that the ideal stresses worked out for a reinforced concrete structure are far from realization in this far from ideal material.

Apart from the objection that the elastic theory, instead of showing economy by cutting down the thickness of the arch ring, would show the very opposite if fully carried out, there are objections of greater weight, objections which strike at the very foundation of the theory as applied to reinforced concrete. In the elastic theory, as in the intricate beam theory commonly used, there is the assumption of an initial unstressed condition of the materials. This is not true of a beam and is still further from the truth in the case of an arch. Besides shrinkage of the concrete, which always produces unknown initial stresses, there is a still more potent cause of initial stress, namely, the settlement of the arch when the forms are removed. If the initial stresses are unknown, ideal determinations of stresses can have little meaning.

The elastic theory stands or falls according as one is able or unable to calculate accurately the deflection of a reinforced concrete beam; and it is an impossibility to calculate this deflection even approximately. The tests cited by Professor Lanza show the utter disagreement in the matter of deflections. Of those tested, two beams which were identical, showed results almost 100% apart. A theory grounded on such a shifting foundation does not deserve serious consideration. Professor Lanza's conclusions, quoted under the twelfth point, have special meaning and force when applied to a reinforced concrete arch;

the actual distribution of the stresses cannot possibly be determined, and complex cloaks of arithmetic cannot cover this fact. The elastic theory, far from being a reliable formula, is false and misleading in the extreme.

The fourteenth point refers to temperature calculations in a reinforced concrete arch. These calculations have no meaning whatever. To give the grounds for this assertion would be to reiterate much of what has been said under the subject of the elastic arch. If the unstressed shape of an arch cannot be determined because of the unknown effect of shrinkage and settlement, it is a waste of time to work out a slightly different unstressed shape due to temperature variation, and it is a further waste of time to work out the supposed stresses resulting from deflecting that arch back to its actual shape.

If no other method of finding the approximate stresses in an arch existed, the elastic theory might be classed as the best available; but this is not the case. There is a method which is both simple and reliable. Accuracy is not claimed for it, and hence it is in accord with the more or less uncertain materials dealt with. Complete safety, however, is assured, for it treats the arch as a series of blocks, and the cementing of these blocks into one mass cannot weaken the arch. Reinforcement can be proportioned in the same manner as for chimneys, by finding the tension exerted to pull these blocks apart and then providing steel to take that tension.

The fifteenth point concerns steel in compression in reinforced concrete columns or beams. It is common practice—and it is recommended in the most pretentious works on the subject—to include in the strength of a concrete column slender longitudinal rods embedded in the concrete. To quote from one of these works:

"The compressive resistance of a hooped member exceeds the sum of the following three elements: (1) The compressive resistance of the concrete without reinforcement. (2) The compressive resistance of the longitudinal rods stressed to their elastic limit. (3) The compressive resistance which would have been produced by the imaginary longitudinals at the elastic limit of the hooping metal, the volume of the imaginary longitudinals being taken as 2.4 times that of the hooping metal."

This does not stand the test, either of theory or practice; in fact, it is far from being true. Its departure from the truth is great

enough and of serious enough moment to explain some of the worst accidents in the history of reinforced concrete.

It is a nice theoretical conception that the steel and the concrete act together to take the compression, and that each is accommodating enough to take just as much of the load as will stress it to just the right unit. Here again, initial stress plays an important part. The shrinkage of the concrete tends to put the rods in compression, the load adds more compression on the slender rods and they buckle, because of the lack of any adequate stiffening, long before the theorists' ultimate load is reached.

There is no theoretical or practical consideration which would bring in the strength of the hoops after the strength of the concrete between them has been counted. All the compression of a column must, of necessity, go through the disk of concrete between the two hoops (and the longitudinal steel). No additional strength in the hoops can affect the strength of this disk, with a given spacing of the hoops. It is true that shorter disks will have more strength, but this is a matter of the spacing of the hoops and not of their sectional area, as the above quotation would make it appear.

Besides being false theoretically, this method of investing phantom columns with real strength is wofully lacking in practical foundation. Even the assumption of reinforcing value to the longitudinal steel rods is not at all borne out in tests. Designers add enormously to the calculated strength of concrete columns when they insert some longitudinal rods. It appears to be the rule that real columns are weakened by the very means which these designers invest with reinforcing properties. Whether or not it is the rule, the mere fact that many tests have shown these so-called reinforced concrete columns to be weaker than similar plain concrete columns, is amply sufficient to condemn the practice of assuming strength which may not exist. Of all parts of a building, the columns are the most vital. The failure of one column will, in all probability, carry with it many others stronger than itself, whereas a weak and failing slab or beam does not put an extra load and shock on the neighboring parts of a structure.

In Bulletin No. 10 of the University of Illinois Experiment Station,* a plain concrete column, 9 by 9 in. by 12 ft., stood an ultimate crushing load of 2 004 lb. per sq. in. Column 2, identical in

* Page 14, column 8.

size, and having four $\frac{5}{8}$-in. rods embedded in the concrete, stood 1 557 lb. per sq. in. So much for longitudinal rods without hoops. This is not an isolated case, but appears to be the rule; and yet, in reading the literature on the subject, one would be led to believe that longitudinal steel rods in a plain concrete column add greatly to the strength of the column.

A paper, by Mr. M. O. Withey, before the American Society for Testing Materials, in 1909, gave the results of some tests on concrete-steel and plain concrete columns. (The term, concrete-steel, is used because this particular combination is not "reinforced" concrete.) One group of columns, namely, *W*1 to *W*3, 10½ in. in diameter, 102 in. long, and circular in shape, stood an average ultimate load of 2 600 lb. per sq. in. These columns were of plain concrete. Another group, namely, *E*1 to *E*3, were octagonal in shape, with a short diameter (12 in.), their length being 120 in. These columns contained nine longitudinal rods, $\frac{5}{8}$ in. in diameter, and $\frac{1}{4}$-in. steel rings every foot. They stood an ultimate load averaging 2 438 lb. per sq. in. This is less than the column with no steel and with practically the same ratio of slenderness.

In some tests on columns made by the Department of Buildings, of Minneapolis, Minn.*, Test *A* was a 9 by 9-in. column, 9 ft. 6 in. long, with ten longitudinal, round rods, ½ in. in diameter, and 1½-in. by $\frac{3}{16}$-in. circular bands (having two ½-in. rivets in the splice), spaced 4 in. apart, the circles being 7 in. in diameter. It carried an ultimate load of 130 000 lb., which is much less than half "the compressive resistance of a hooped member," worked out according to the authoritative quotation before given. Another similar column stood a little more than half that "compressive resistance." Five of the seventeen tests on the concrete-steel columns, made at Minneapolis, stood less than the plain concrete columns. So much for the longitudinal rods, and for hoops which are not close enough to stiffen the rods; and yet, in reading the literature on the subject, any one would be led to believe that longitudinal rods and hoops add enormously to the strength of a concrete column.

The sixteenth indictment against common practice is in reference to flat slabs supported on four sides. Grashof's formula for flat plates has no application to reinforced concrete slabs, because it is derived

* *Engineering News*, December 3d, 1908.

for a material strong in all directions and equally stressed. The strength of concrete in tension is almost nil, at least, it should be so considered. Poisson's ratio, so prominent in Grashof's formula, has no meaning whatever in steel reinforcement for a slab, because each rod must take tension only; and instead of a material equally stressed in all directions, there are generally sets of independent rods in only two directions. In a solution of the problem given by a high English authority, the slab is assumed to have a bending moment of equal intensity along its diagonal. It is quite absurd to assume an intensity of bending clear into the corner of a slab, and on the very support equal to that at its center. A method published by the writer some years ago has not been challenged. By this method strips are taken across the slab and the moment in them is found, considering the limitations of the several strips in deflection imposed by those running at right angles therewith. This method shows (as tests demonstrate) that when the slab is oblong, reinforcement in the long direction rapidly diminishes in usefulness. When the ratio is 1 : 1½, reinforcement in the long direction is needless, since that in the short direction is required to take its full amount. In this way French and other regulations give false results, and fail to work out.

If the writer is wrong in any or all of the foregoing points, it should be easy to disprove his assertions. It would be better to do this than to ridicule or ignore them, and it would even be better than to issue reports signed by authorities, which commend the practices herein condemned.

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PAPERS AND DISCUSSIONS

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THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE TERMINAL STATION-WEST.*

By B. F. Cresson, Jr., M. Am. Soc. C. E.

To be Presented April 6th, 1910.

Location of Work.—The area covered by the work of the Terminal Station-West is bounded as follows: By the east line of Ninth Avenue; by the south side of 31st Street to a point about 200 ft. west of Ninth Avenue; by a line running parallel to Ninth Avenue and about 200 ft. therefrom, from the south side of 31st Street to the boundary line between the 31st and 32d Street properties; by this line to the east line of Tenth Avenue; by the east line of Tenth Avenue to the boundary line between the 32d and 33d Street properties; by this line to the east line of Ninth Avenue. The area is approximately 6.3 acres.

House-Wrecking.—The property between Ninth and Tenth Avenues was covered with buildings, 94 in number, used as dwelling and apartment houses and church properties, and it was necessary to remove these before starting the construction. Most of the property was bought outright by the Railroad Company, but in some cases condemnation proceedings had to be instituted in order to acquire possession. In the case of the property of the Church of St. Michael, fronting on Ninth

* This paper is written for the purpose of describing in detail that portion of the Pennsylvania Railroad Company's Extension into New York City known as The Terminal Station-West, referred to in the paper on "The New York Tunnel Extension of the Pennsylvania Railroad—The North River Division," by Charles M. Jacobs, M. Am. Soc. C. E.

Avenue, 31st and 32d Streets, the Railroad Company agreed to purchase a plot of land on the south side of 34th Street, west of Ninth Avenue, and to erect thereon a church, rectory, convent, and school, to the satisfaction of the Church of St. Michael, to hand over these buildings in a completed condition, and to pay the cost of moving from the old to the new buildings, before the old properties would be turned over to the Railroad Company.

The house-wrecking was done by well-known companies under contract with the Railroad Company. These companies took down the buildings and removed all the materials as far as to the level of the adjacent sidewalks. The building materials became the property of the contractors, who usually paid the Railroad Company for the privilege of doing the house-wrecking. The work was done between April and August, 1906, but the buildings of the Church of St. Michael were torn down between June and August, 1907.

The bricks were cleaned and sold directly from the site, as were practically all the fixtures in the buildings. The stone fronts were broken up and left on the premises. Some of the beams were sold on the premises, but most of them were sent to the storage yards. Some of the lath and smaller timber was sold for firewood, but most of it was given away or burned on the premises.

Contracts and Agreements.—The main contract, awarded to the New York Contracting Company-Pennsylvania Terminal on April 28th, 1906, included about 502 000 cu. yd. of excavation (about 90% being rock), 17 820 cu. yd. of concrete walls, 1 320 000 lb. of structural steel, 638 000 ft., B. M., of framed timber, etc., etc.

This contract was divided into two parts: "Work In and Under Ninth Avenue" and "Work Between Ninth and Tenth Avenues," and unit prices were quoted for the various classes of work in each of these divisions. The prices quoted for excavation included placing the material on scows supplied by the Railroad Company at the pier at the foot of West 32d Street, on the North River; there was a clause in the contract, however, by which the contractor could be required to make complete disposal of all excavated material at an additional unit price, and this clause was enforced on January 1st, 1909, when about 94% of the excavation had been done.

For the purpose of disposing of the excavated material in the easterly portion of the Terminal, the New York Contracting Company-

Pennsylvania Terminal had excavated under Ninth Avenue a cut which came to the grade of 32d Street about midway between Ninth and Tenth Avenues, and a trestle was constructed from this point over Tenth Avenue and thence to the disposal pier at the foot of West 32d Street.

On May 11th, 1906, the work of excavation was commenced on the east side of Ninth Avenue, and on July 9th, 1906, on the south side of 31st Street, between Ninth and Tenth Avenues. From the beginning, the excavation was carried on by day and night shifts, except on Sundays and holidays, until January, 1909, except that during the period from November, 1907, to October, 1908, the night shift was discontinued.

Geology.—The rock encountered may be classed as "gneiss"; its character varied from granite to mica schist. It was made up of quartz, feldspar, and mica, and there were also some isolated specimens of pyrites, hornblend, tourmaline, and serpentine. On the south side of the work, just west of Ninth Avenue, there were excellent examples of "contortions" of veins of quartz in the darker rock. On the east side of Ninth Avenue, near the north end of the work, glacial marks were found on the rock surface. The general direction of the stratification was north 5° west, and the general incline about 60° with the horizontal. As a rule, the rock broke sharply along the line of stratification. On the south side it broke better than on the north side, where it was usually softer and more likely to slide; and this, together with the fact that in winter it was subject to alternate freezing and thawing and in summer to the direct rays of the sun, made it rather difficult to get a good foundation for the retaining walls.

Work In and Under Ninth Avenue.

General Description.—The work involved the excavation of about 375 ft. of the full width of Ninth Avenue to an average depth of about 58 ft., and the construction over this area of a steel viaduct, the deck of which was about 24 ft. below the surface, for the ultimate support of the Ninth Avenue structures.

The following estimated quantities appear in the contract: Excavation of rock, 72 600 cu. yd.; excavation of all materials except rock, 9 300 cu. yd.; concrete (1:3:6) in abutments, etc., 1 680 cu. yd.; timber, 504 000 ft., B. M.; structural steel, 1 320 000 lb., etc.

While this excavation was being done it was necessary to support and maintain the three-track elevated railway structure of the Interborough Rapid Transit Company, of which 18 columns, or a length of about 340 ft., were affected, the two-track surface railway structure of the New York City Railway Company, and various pipes, sewers, and conduits, and to maintain all surface vehicular and pedestrian traffic. All structures were left in place with the exception of the pipes, most of which were temporarily cut out. The 48-in. brick sewer in the center of Ninth Avenue was broken, and the sewage was pumped across the excavation through a smaller pipe.

The general method adopted was as follows: The east and west sides of the avenue were closed, vehicular traffic was turned into the center, and a trestle for pedestrians was constructed west of the westerly elevated railway columns. All structures were then supported on transverse girders, running across the avenue, below the surface, and these rested on concrete piers on the central rock core. The sides of the avenue were then excavated to sub-grade, and the permanent steel viaduct was erected on both sides of the avenue as close as possible to the central rock core. The weight of all structures was then transferred to the permanent steel viaduct, erected on the sides of the avenue, by timber bents under the transverse girders resting on the permanent steel viaduct, and all weight was thus taken off the central rock core. This core was then excavated to sub-grade, the permanent viaduct was completed, and all structures were placed on its deck, using concrete piers and timber bents.

The design and erection of the permanent steel viaduct and the permanent foundations on its deck were done under another contract, apart from the North River Division work, and are not described in this paper.

Elevated Railway Structure of the Interborough Rapid Transit Company.—The Ninth Avenue Elevated Railway was built between 1877 and 1880 as a two-track structure, the design being such as to permit a third or central track to be added later, and this was built in 1894. It is supported on columns under the outside tracks, about 43 ft. from center to center longitudinally and 22 ft. 3 in. from center to center transversely, the central track being carried by transverse girders between the columns.

The columns carrying the structure are of fan top design, with the

points of bearing near the extremities at the top; each of the outside tracks is supported on two longitudinal latticed girders and the central track on two plate girders; between the columns, transverse girders are spliced to the outside track cross-frames, and carry the central track system. It was not thought desirable to put brackets on the columns near the street level to support the structure temporarily, and, as there is an expansion joint at each column, and as the transverse girders carrying the central track system are not rigidly attached to the longitudinal girders carrying the outside tracks, the central track could not be supported by supporting the outside tracks; therefore, independent supports for each track, in the form of overhead girders, had to be provided. The columns rest on brick piers, each having four 2-in. anchor-bolts. The brick foundations on the west side are wide in order to allow a 24-in. water main to pass directly beneath the columns. The foundations are usually on rock.

Fig. 1, Plate XXXIV, shows the elevated railway structure and the street surface prior to the commencement of the work.

The east track is used for north-bound local trains, the west track for south-bound local trains, and the central track for south-bound express trains between 7 and 9.30 A. M. and for north-bound express trains between 2.30 and 7 P. M. It is said that an average of 90 000 passengers are carried over this structure every 24 hours.

Surface Railway Structure of the New York City Railway Company.—This is an electric surface railway of the ordinary type, the rail and slot being bedded in concrete, with cast-iron yokes every 5 ft. There are manholes every 100 ft., and cleaning-out holes every 15 ft. Power conduits are bedded in the concrete on the east side of the east track.

Forty-eight-Inch Brick Sewer.—This sewer was in the center of Ninth Avenue, with the invert about 12 ft. below the surface, and manholes about 100 ft. apart, and had to be abandoned in this position to allow the transverse girders to be put in place to carry all structures while the excavation was being done.

Twenty-four-Inch Cast-Iron Water Main.—This water main was laid under the west elevated railway columns, with its top about 3 ft. below the surface, a space being left for it in the brick foundations, and a large column base casting being used to span it. Valves were installed, one north of 33d Street and one south of 31st Street, prior

Fig. 1.

Fig. 3.

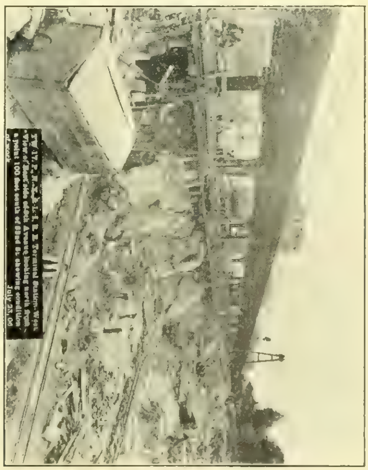


Fig. 2.

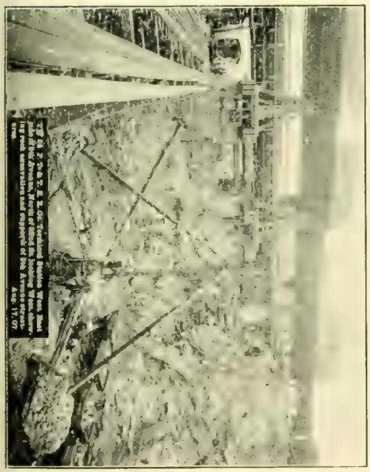


Fig. 4.

to excavating near the pipe, so that if it was broken the water could be shut off promptly.

Street Surface.—It was the original intention to close and excavate the east side of the avenue and to erect there a street-traffic trestle before closing the west side, but, at the contractor's request, both sides were closed, and all vehicular traffic was turned into the center. A light trestle on the west side of the avenue provided for pedestrian traffic.

Other Sub-surface Structures.—There were various gas mains, water mains, electric conduits, manholes, hydrants, etc., in the avenue, and most of these were cut out temporarily, at the contractor's request, to be replaced subsequently.

Supports for Elevated Railway Structure.—As stated previously, the central track had to be supported independently.

The overhead girders, known as girders "B", were therefore designed as shown on Fig. 1, and put in place as shown on Figs. 2 and 3. The outside tracks were blocked directly on these girders, and the central track was supported by blocking up the transverse girders on I-beams placed between the girders "B"; and no blocking was placed between the girders "B" and the longitudinal girders carrying the central track. The weight on each column was assumed to be 172 000 lb.

Supports for Surface Railway Structure.—A uniform load of 3 000 lb. per lin. ft. of single track, with the weight of a car at 39 000 lb., was assumed. Several feet of earth, between the structure and the rock, were mined out, and the structure was supported on I-beams and posts, and ultimately on the transverse girders by using timber bents under the I-beams, as shown on Fig. 3.

Water Mains and Sewer.—Cradles were designed for the support of the 48-in. and 24-in. water mains, resting on the transverse girders, and the 48-in. cast-iron sewer on the east side of the avenue was carried on I-beams bracketed to the ends of the transverse girders, as shown on Figs. 1 and 2.

Girders "C."—The transverse girders below the street surface, referred to above, were known as girders "C," and they were put in place at first resting on concrete piers on the central core; the weight of all structures was placed on them while the sides of the avenue were being excavated, and the sides of the viaduct were being built.

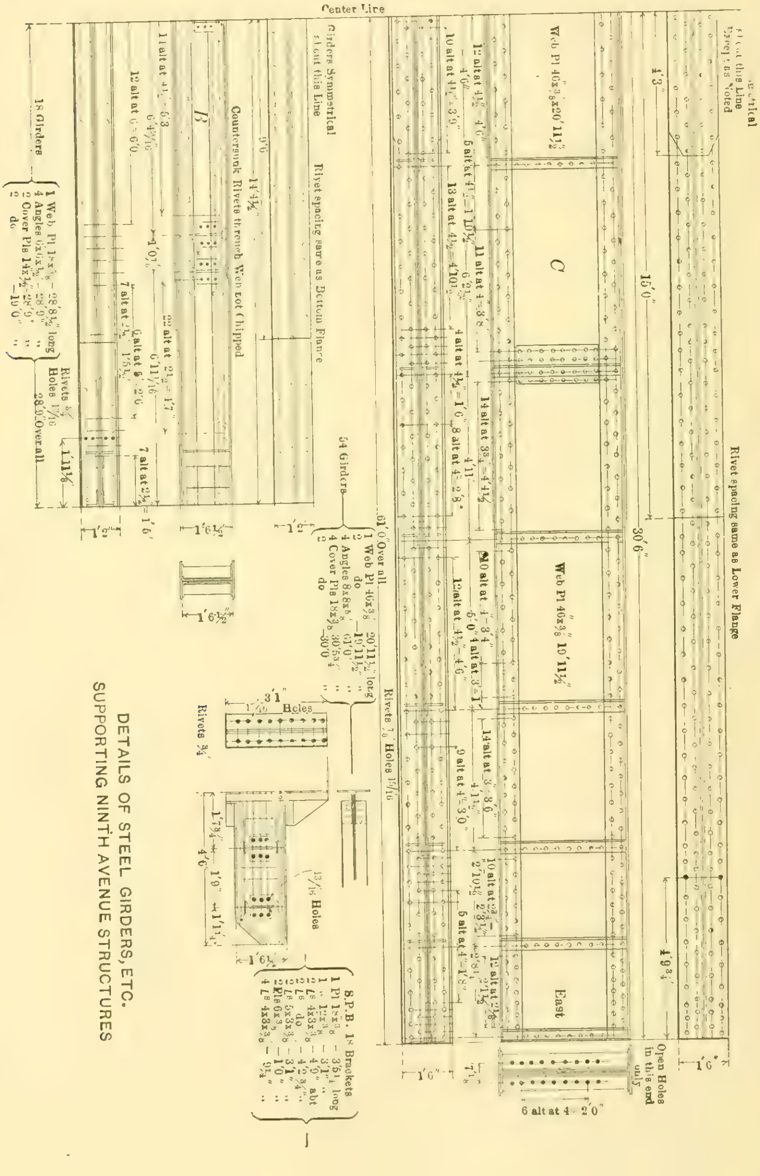
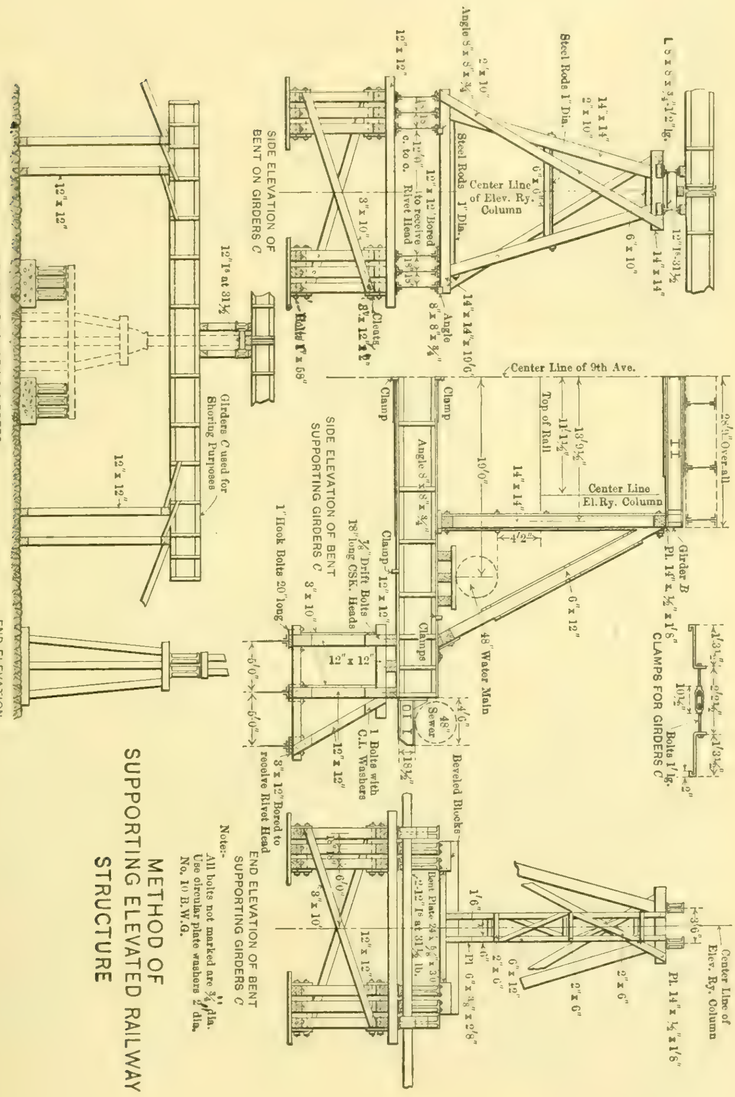


FIG. 1.

DETAILS OF STEEL GIRDERS, ETC. SUPPORTING NINTH AVENUE STRUCTURES



METHOD OF SUPPORTING ELEVATED RAILWAY STRUCTURE

FIG. 2.

The ends of these girders were then picked up on the sides of the viaduct, and, spanning the central rock core, carried all structures while the core was being excavated and the viaduct completed. New foundations were then placed on the deck of the viaduct to carry all structures.

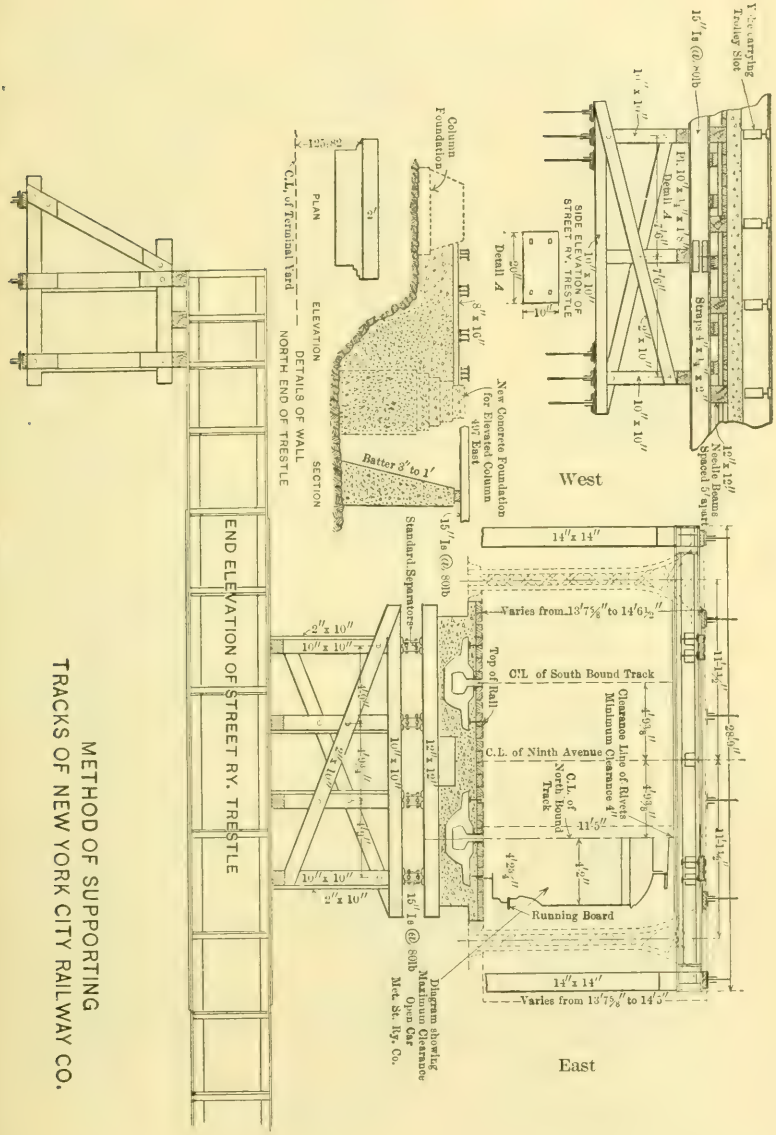
Fifty-four of these girders were required, each weighing about 19 000 lb. The bents carrying the ends of these girders on the sides of the viaduct are shown on Fig. 2. They were of long-leaf yellow pine. These girders were located so that a cradle could be laid on them east of the elevated railway structure to carry a proposed 48-in. cast-iron water main.

Girders "B."—Eighteen of these girders were required, each weighing about 6 000 lb. The timber bents supporting these girders, shown on Fig. 2, were of long-leaf yellow pine.

The total weight, including the elevated railway structure, surface railway structure, pipes, etc., supported during the work, amounted to about 5 000 tons.

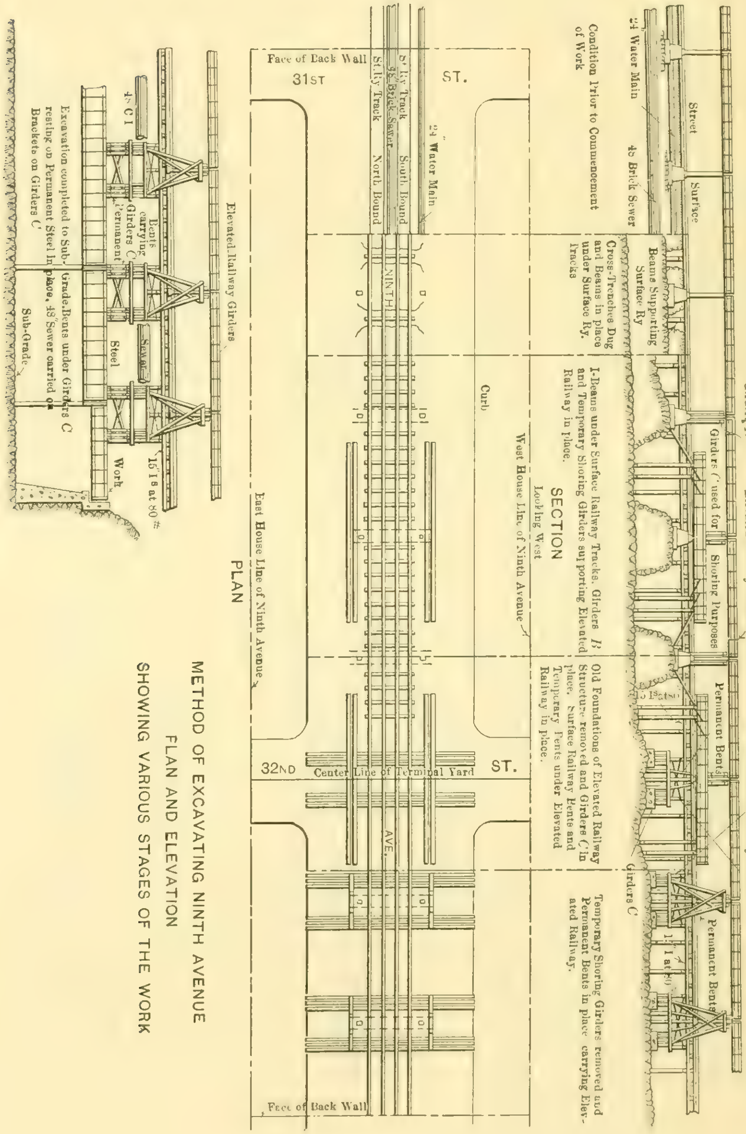
Details of the Work.—The method in general is shown on Figs. 4 and 5. At first the east side of the avenue was closed and excavated down to rock, the earth was mined out under alternate yokes of the surface railway structure, and temporary posts were placed under the yokes to support the structure while the remainder of the earth was being removed. Then needle-beams and posts were placed under each yoke. The concrete forming the track structure was then enclosed with planking to prevent it from cracking and falling. I-beams were then placed under the needle-beams carrying the structures, and these were carried on posts; they were changed alternately until the excavation had been taken out to a depth of about 16 ft. below the surface. In placing these I-beams, heavier blocking was used in the center of the span than at the ends where the bents would come, to prevent the subsidence of the track owing to the sag in the I-beams. As much excavation, to a depth of about 20 ft., was taken out adjoining the elevated railway foundations as could be done with safety. Fig. 2, Plate XXXIV, shows this condition of the work. The 48-in. brick sewer was broken, and the sewage was pumped across the excavation.

The overhead girders "B" were then put in place, and two of the girders "C" were used as temporary shoring girders at each column.



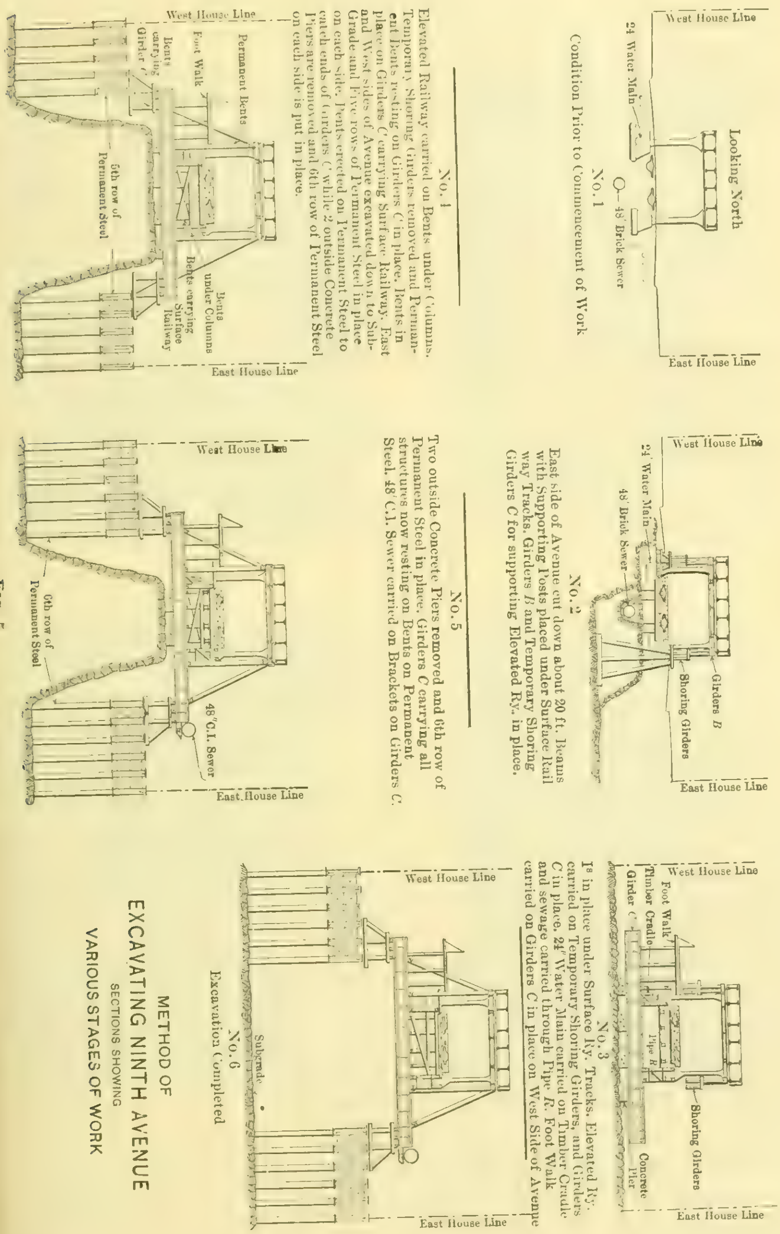
METHOD OF SUPPORTING TRACKS OF NEW YORK CITY RAILWAY CO.

FIG. 3.



METHOD OF EXCAVATING NINTH AVENUE
PLAN AND ELEVATION
SHOWING VARIOUS STAGES OF THE WORK

FIG. 4.



Looking North
West House Line
East House Line
24' Water Main
48' Brick Sewer
No. 1
Condition Prior to Commencement of Work
Girders B
Shoring Girders
No. 2
East side of Avenue cut down about 20 ft. Beams with Supporting Posts placed under Surface Railway Tracks. Girders B and Temporary Shoring Girders C for supporting Elevated Ry. in place.
Foot Walk
Timber Cradle
Girder C
Pipe R
Concrete Pier
No. 3
Is in place under Surface Ry. Tracks. Elevated Ry. carried on Temporary Shoring Girders, and Girders C in place. 24' Water Main carried on Timber Cradle and sewage carried through Pipe R. Foot Walk carried on Girders C in place on West Side of Avenue
Permanent Bents
Foot Walk
Bents carrying Girder C
Bents under Columns
Bents carrying Surface Railway
5th row of Permanent Steel
No. 4
Elevated Railway carried on Bents under Columns. Temporary Shoring Girders removed and Permanent Bents resting on Girders C in place. Bents in place on Girders C carrying Surface Railway. East and West sides of Avenue excavated down to Sub-Grade and Five rows of Permanent Steel in place on each side. Bents erected on Permanent Steel to catch ends of Girders C while 2 outside Concrete Piers are removed and 6th row of Permanent Steel on each side is put in place.
48" C.I. Sewer
6th row of Permanent Steel
No. 5
Two outside Concrete Piers removed and 6th row of Permanent Steel in place. Girders C carrying all structures now resting on Bents on Permanent Steel. 48" C.I. Sewer carried on Brackets on Girders C.
Subgrade
No. 6
Excavation Completed
METHOD OF
EXCAVATING NINTH AVENUE
SECTIONS SHOWING
VARIOUS STAGES OF WORK

FIG. 5.

These, as shown by Fig. 3, Plate XXXIV, were placed parallel to the elevated railway, with blocking between them and the girders "B." Double bents, independent of each other, were placed under the ends of these temporary shoring girders, and these were braced securely to prevent possible dislodgment during the removal of the rock. The weight of the structure was then taken by jacking up the girders near the bents until the column was lifted off the old foundation; blocking was put in between the girders and the bents during the jacking, so that when the jacks were released the base of the column was still clear of the old foundation. One 80-ton jack was used for this purpose, and the general method is shown by Fig. 1, Plate XXXIX.

Temporary raker braces were placed against the structure to prevent lateral movement. Four sets of these temporary shoring girders were used in this manner, two sets starting at the north end and two sets at about the middle of the work, and these sets were moved south as they were released.

The columns being thus supported on temporary shoring girders, the old foundations were removed and the excavation was taken down to a level about 16 ft. below the surface.

Two sets of three of the girders "C" were then put in place under the avenue at each column, each set being placed on four concrete piers 6 ft. square with spaces of 4 ft. between them, so that the outside of the outside pier would be 18 ft. from the center of the avenue and 32 ft. from the house line. This is shown on Fig. 5 and on Fig. 3, Plate XXXIV. Four small piers were used, as they could be more easily removed than one continuous pier. The girders "C" were set to line and grade, and the piers were built under them, great care being taken to get the concrete well under the girders so as to give a firm bearing.

After these girders "C" were in place it was necessary to remove the temporary shoring girders before the bents could be erected on girders "C" to support girders "B," being in the same plane; and provision had to be made to support the structure while this was being done. Therefore, double bents were erected directly beneath the columns, as shown by Figs. 2, 4, and 5, and by Fig. 3, Plate XXXIV. These were built with their sills resting on the girders "C," and blocking was put in between the sills and the rock to carry the full weight of the structure. Later, when the weight of the structure was carried

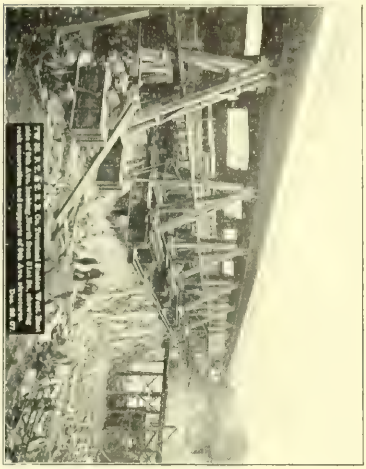


FIG. 1.

FIG. 2.

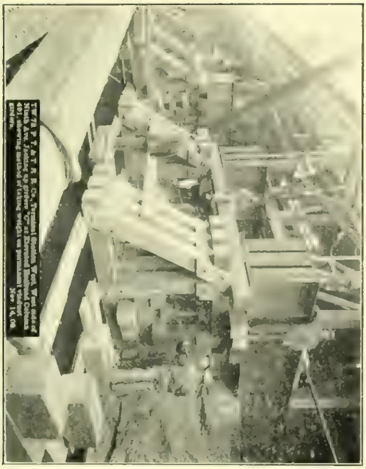


FIG. 3.

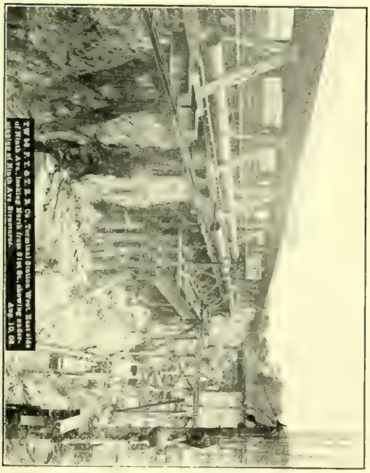


FIG. 4.

on the permanent bents, this blocking was knocked out, but the bents were left in to carry the weight of the column itself, which was swinging more or less from the structure above. The weight of the structure was placed on these bents directly beneath the columns by jacking up the temporary girders again, putting blocking between the bents and the base of the columns, and taking out the blocking which had been put in previously under the temporary shoring girders. The 24-in. water main was carried over the excavation on cables from the temporary shoring girders, except when they were being jacked up, at which time posts were placed beneath it.

Anchor-bolts were put in place between the column bases and the bents directly beneath, in order to increase the lateral stiffness, and raker braces were also used. This having been done, the temporary shoring girders were moved south to the next column, where the process was repeated. The timber bents, shown in detail by Fig. 2, were then put in place as shown by Figs. 4 and 5, and by Fig. 3, Plate XXXIV. These bents were framed as tightly as possible, using generally a 20-ton jack, and they were erected simultaneously at each pair of columns. The weight was taken on these columns by jacking up directly beneath the column base and taking out the blocking between this base and the bent directly beneath the column. On releasing the jack the weight was transferred to the permanent timber bents, and the east and west columns of each pair were transferred on the same day. One 80-ton jack was used on the easterly columns and two were necessary on the westerly columns, one on each side of the 24-in. water main. The raker braces of these permanent bents were not framed as tightly as the main posts, in order that the main post should carry the entire weight and the raker braces merely steady the structure.

Timber bents were erected on girders "C" to carry the I-beams under the surface railway structure, as shown on Fig. 3, and all temporary posts under these I-beams were removed. The bents were framed with a jack, as tightly as possible, and very little settlement of the track occurred.

A cradle was then built under the 24-in. water main and placed on girders "C," and, as a temporary footwalk had been constructed on the west side of the avenue, it will be seen that all structures were thus carried on girders "C."

All structures were put on the girders "C" before continuing the

excavation on the sides of the avenue because, in case of a slide of rock, there would be less danger than to individual structures. The outside piers, on which the girders "C" rested, might even be lost, without affecting the stability of the structure, and posting could readily be done beneath these girders in case of necessity.

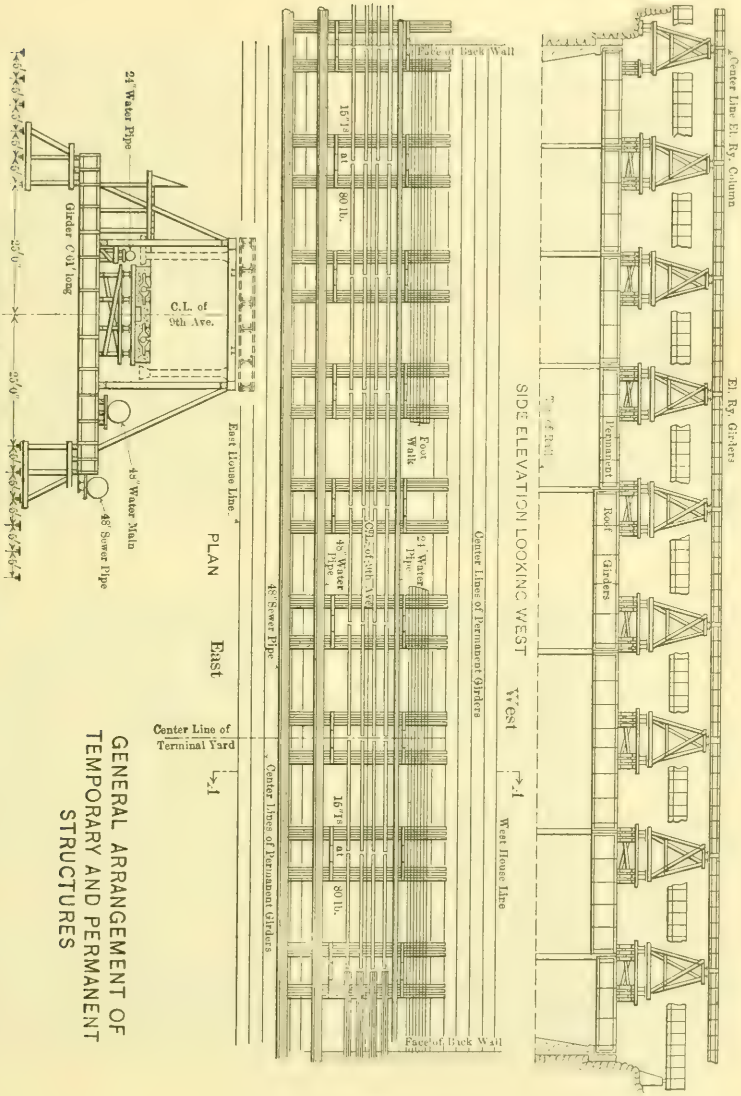
A very careful record of levels, taken on the elevated railway columns, was kept, observations being made during each jacking up and at least twice a week during the progress of the work. The columns were usually kept about ½ in. high so as to allow for compression in the timber bents.

As a rule, no jacking of the elevated railway structure was done while trains were passing over, and trains were flagged during the operation. There was generally very little delay, as all jacking was done between 10.30 A. M. and 2.30 P. M., when the traffic was lightest, and frequently the jacking was done between trains, causing no delay whatever. Steel clamps were placed, three on the top and three on the bottom of each set of the girders "C," to bind them together and cause them to act as a unit.

All structures then being supported on girders "C," which were carried on four concrete piers resting on the central rock core, the excavation on the sides of the avenue was continued down to sub-grade and the east and west portions of the concrete north abutment were constructed. The central rock core was about 36 ft. wide on the top and 45 ft. wide on the bottom, and at the center of 32d Street it was about 42 ft. high.

It was the original intention to excavate a sufficient width of the sides of the avenue to erect six rows of the permanent steel viaduct, 5 ft. from center to center, and this was done on the south portion of the work. On the north portion, however, the rock was of poor quality, and it was thought best to excavate for only five rows at first, to erect the five rows of permanent steel and put the timber bents in place under the ends of the girders "C," in order to give them some support while the outside concrete piers were being removed and the excavation was being widened out to permit the erection of the sixth row. Additional raker braces were put in these bents temporarily, and were removed when the sixth row of steel had been erected. This is shown on Figs. 4 and 5.

Fig. 4, Plate XXXIV, and Fig. 1, Plate XXXV, show the struc-



GENERAL ARRANGEMENT OF TEMPORARY AND PERMANENT STRUCTURES

FIG. 6.

tures supported on the central rock core and the excavation on the east side to permit of the erection of the permanent viaduct girders. Fig. 1, Plate XXXV, shows also the easterly portion of the concrete north abutment. Fig. 2, Plate XXXV, shows five rows of the permanent viaduct girders erected on the east side of the work.

The excavation of the sides of the avenue having been completed, and six rows of permanent viaduct girders erected on both sides, timber bents, as shown on Figs. 2, 4, 5, and 6, were erected on this steel to support the ends of the girders "C" and carry the structure while the rock core was being excavated. Fig. 3, Plate XXXV, shows the method of taking the weight on these bents. Four 80-ton jacks were used, and oak blocks were placed on the top of each jack to transmit pressure to a temporary oak cap under the girders "C" independent of the bents; all four of these jacks were operated simultaneously, and the girders "C" were lifted off the bents and clear of the concrete piers. Oak filling pieces were then inserted between the bents and the girders "C," so that when the jacks were released the girders "C" were clear of the concrete piers. Fig. 3, Plate XXXV, shows that the girders have been lifted off the piers. Elevations were taken on each set of girders during each operation, and careful observations were made on the elevated railway columns. Where the rock was very close to these bents, the open space between the posts was filled with blocking so that there would be less danger of the bent shifting if struck by blasted materials. Fig. 3, Plate XXXV, shows one of these bents filled with blocking.

All structures being carried on girders "C," which, in turn, were carried on the sides of the permanent viaduct, the central core was excavated. Fig. 4, Plate XXXV, and Figs. 1, 2, 3, and 4, Plate XXXVI, show various views of the work at this stage.

The central portion of the viaduct was then erected, and, using concrete piers and timber bents, all structures were placed on its deck. Fig. 3, Plate XXXVI, shows the piers under the elevated railway columns prior to the removal of girders "C."

During the latter part of 1908 a 48-in. cast-iron water main was laid by the city on a cradle built by the Railroad Company on girders "C" on the east side of the avenue. This is part of the high-pressure system, and the location and elevation of this water main were taken into consideration when the underpinning was designed. This main,

PLATE XXXVI.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
CRESSON ON
TERMINAL STATION-WEST: PENNSYLVANIA RAILROAD.

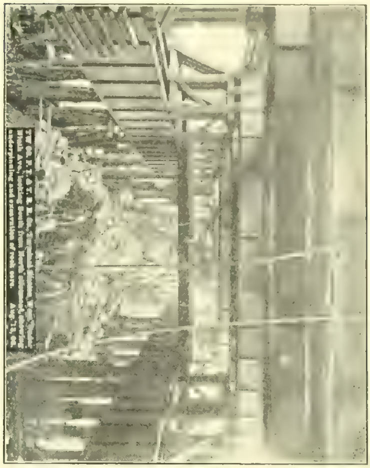


FIG. 1.

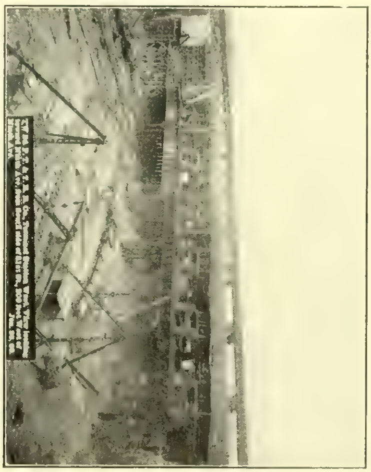


FIG. 2.

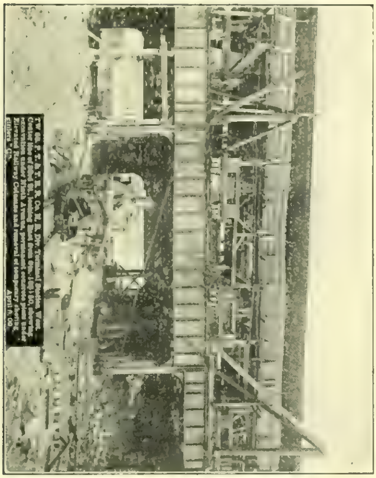


FIG. 3.

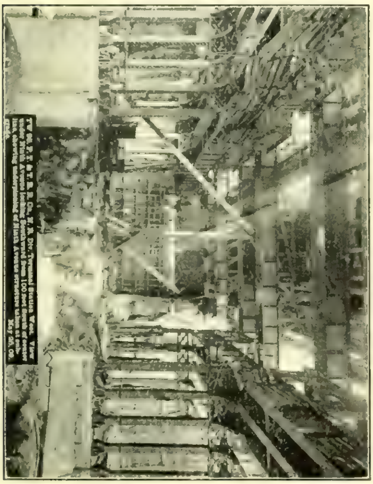


FIG. 4.

and the 48-in. cast-iron sewer bracketed to girders "C," are shown on Fig. 4, Plate XXXV.

Elevations had been taken on marks on the elevated railway columns between 30th and 34th Streets at the time the original surveys were made, in 1902, and these marks were used to test the level of the structure during the progress of the excavation.

At the extreme south end of the work the procedure was changed. The east side was excavated down to sub-grade, the east portion of the south abutment was constructed, and six rows of the permanent steel viaduct were erected. Very little excavation had been done on the west side of the avenue at the south end of the work, and it would have delayed the completion of the work to have waited for the excavation for and the construction of the west portion of the south abutment and the erection of the steel; therefore, instead of supporting the girders "C" on the central rock core, the east ends were taken up on the permanent viaduct girders, and the west ends were supported on a concrete pier on the rock. The central portion of the avenue was excavated in advance of the west portion. The permanent viaduct girders were put in place from east to west across the avenue, and the girders "C" were supported on the deck of the permanent viaduct approximately under the west elevated railway columns before the west portion of the avenue was excavated, the central portion of the south abutment having been constructed before the west portion. This procedure was adopted only at the north girders "C" at elevated railway column No. 488, the south set of girders "C" being on the rock immediately south of the south abutment. Figs. 2 and 4, Plate XXXVI, and Fig. 2, Plate XXXIX, show various stages of the work at the south end.

It was made a practice all through the work to transfer the weight of the structures very positively from one support to another by lifting them bodily by jacks, and putting in filler pieces before releasing the jacks, not trusting to wedging to transfer the loads. In fact, apart from the boxing-in of the surface railway concrete, no wedges whatever were used. This appears to have been a decided advantage, for, with the constant pounding of trains on the elevated railway and the jarring due to heavy trucks on the pavement blocks, it is very likely that wedging would have become loosened and displaced, whereas, with blocking, there was little or no tendency toward displacement due to

vibration. Although the vibration of the structure, when a long length was supported on girders "C" resting on the permanent viaduct girders on the sides of the avenue, appeared to be considerable, not only vertically but transversely, very careful observation showed that the sag in the girder "C" due a live load of three elevated railway trains, one surface railway car, and one heavy truck, amounted to $\frac{1}{8}$ in. The sideway vibration did not amount to more than $\frac{1}{32}$ in. on either side of the normal position. More vibration was caused by heavy trucks and wagons going over the stone pavement than by the elevated railway trains or surface cars.

No blasting was done near the supports of the elevated railway structure while trains were passing over it, and occasionally trains were stopped during a heavy or uncertain blast. A watchman on the surface, day and night, and at first one and later two flagmen on the elevated railway structure, were on duty at all times, reporting to the Interborough Rapid Transit Company, by whom they were employed. Log mats and timber protection for the girders and the columns of the permanent viaduct were used, as shown by Figs. 1 and 4, Plate XXXVI, during the excavation of the rock core, and timber was also used to protect the face of the completed portions of the concrete abutments.

In excavating the sides of the avenue, the rock broke better on the east than on the west side, where large seams developed and some slides occurred.

Abutments.—As shown on Fig. 7, the face of the north abutment has a batter of 2 in. to the foot, and the face of the south abutment has a variable batter, the base being on a grade and the bridge seat being level, and both maintaining a uniform distance from the center of the Terminal Yard. The back walls of the abutments were not built until the steel had been put in place.

No attempt was made to water-proof these abutments, but, in the rear of the wall, open spaces were left, about 6 ft. from center to center, which were connected with drain pipes at the base of and extending through the wall, for the purpose of carrying off any water that might develop in the rock. These drains were formed by building wooden boxes with the side toward the rock open and the joints in the boxes and against the rock plastered with mortar in advance of the wall. A hose was used to run water through these drains during

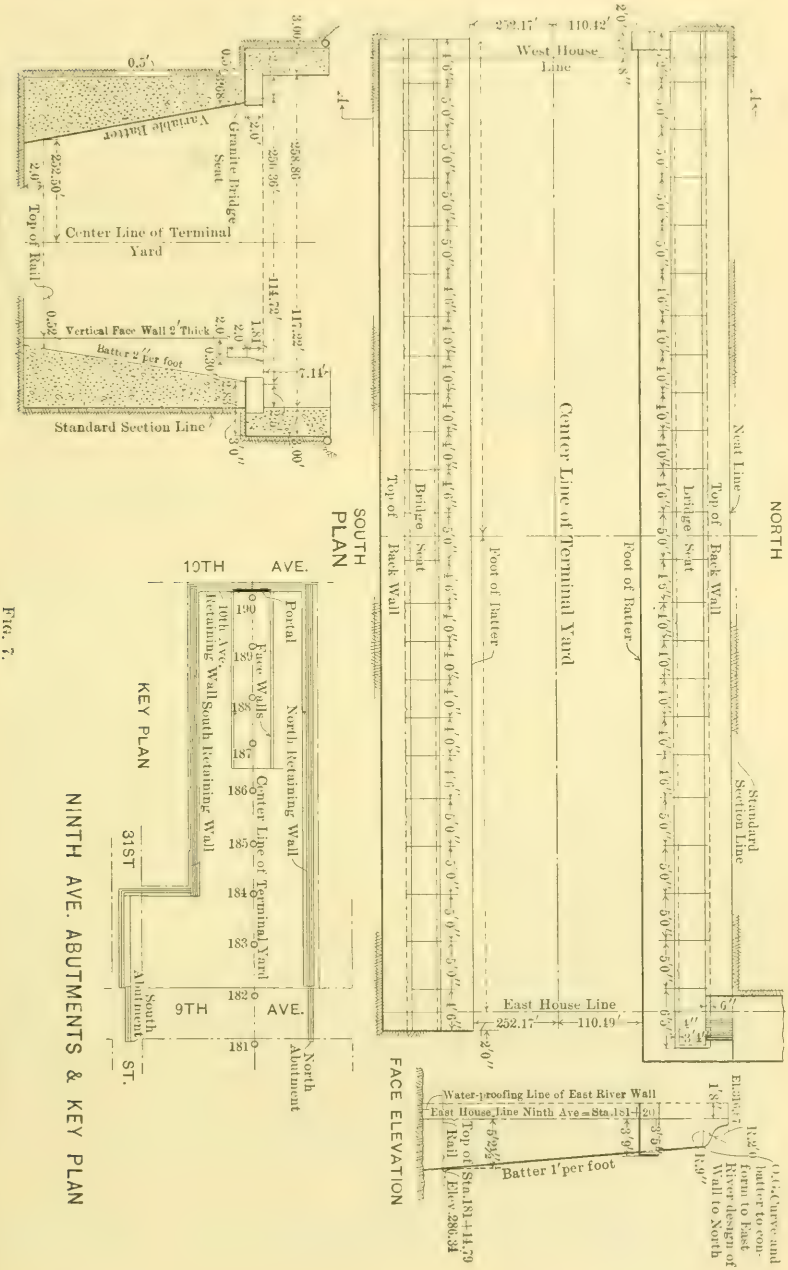


FIG. 7.

NINTH AVE. ABUTMENTS & KEY PLAN

the placing of the concrete, for the purpose of washing out any grout which might run into them. Each box was washed out at frequent intervals, and there was no clogging of the drains whatever. This method of keeping the drains open was adopted and used successfully for the entire work. The abutments were built of concrete, and the mixture was 1 part of cement, 3 parts of sand, and 6 parts of broken stone.

The concrete was mixed in a No. 3 Ransome mixer, and was placed very wet. No facing mixture or facing diaphragms were used, but the stone was spaded away from the face of the wall as the concrete was laid. Chutes were used inside the form, if the concrete had to drop some distance. Work was continued day and night, without any intermission, from the time of commencement to the time of completion of each section.

The face of the concrete wall was rubbed and finished in a manner similar to that used on the walls between Ninth and Tenth Avenues, as described later.

Fig. 2, Plate XXXIX, shows the east and central portions of the south abutment, completed and carrying the permanent viaduct, and the excavation completed for the west portion.

Work Between Ninth and Tenth Avenues.

General Description.—The work involved the excavation of about 5.4 acres, between the west house line of Ninth Avenue and the east house line of Tenth Avenue, to an average depth of about 50 ft., the construction of a stone masonry portal at Tenth Avenue leading to the River Tunnels, and the construction around the site of the concrete retaining and face walls.

The following estimated quantities appear in the contract: Excavation of rock in trenches, 3 400 cu. yd.; excavation of rock in pit, 377 000 cu. yd.; excavation of all materials except rock in trenches, 6 500 cu. yd.; excavation of all materials except rock in pit, 34 000 cu. yd.; concrete, 1:3:6, in retaining walls, 4 580 cu. yd.; concrete, 1:3:6, in face walls, 7 460 cu. yd.; concrete, 1:2:3, with ¾-in. stone, in face walls, 4 100 cu. yd.; stone masonry in portal, 247 cu. yd., etc., etc.

As previously stated, the contract price included the placing of all excavated material on scows at Pier 62, North River. Prior to this

contract this pier had been used by the New York Contracting Company-Pennsylvania Terminal, for the disposal of excavated material from east of Ninth Avenue. In order to get the material to the pier, the contractor had excavated a cut under Ninth Avenue which came to the grade of 32d Street about midway between Ninth and Tenth Avenues, and a trestle was constructed from this point over Tenth Avenue and thence to the pier. Fig. 2, Plate XXXIV, shows the east end of this cut, and Fig. 1, Plate XXXVII, shows the trestle, looking east from Tenth Avenue.

A 30-ton steam shovel was brought to the south side of the work, and commenced operating on July 9th, 1906. After working there about a month, the earth had been practically stripped off the rock, and the shovel was moved over to the north side where it excavated both earth and rock until August 10th, 1907.

At three points south of 32d Street and at one point north of 32d Street near Tenth Avenue, cuts were made in the rock to sub-grade, and from these cuts, together with the cuts on the west side of Ninth Avenue, all widening out was done and the excavation was completed. Fig. 1, Plate XXXVII, shows the excavation of the three cuts on the south side of 32d Street, the steam shovel operating on the north side of that street, and the material-disposal tracks and trestle. Fig. 3, Plate XXXIX, shows the cuts joined up and the excavation along the south side practically completed.

On the north side of the work, between Stations 182 + 90 and 183 + 65, the rock was low, and provision had to be made for maintaining the yards to the north of the site. Therefore a rubble-masonry retaining wall was built, with the face about 2 ft. north of the face of the proposed concrete wall which was to be put in later. On the same side of the work, between Stations 188 + 24 and 188 + 46, the rock was exceedingly poor, and as a small frame house on the adjoining lot was considered to be in an unsafe condition, a rubble masonry retaining wall was built. As the building adjoining the south side of the work at Tenth Avenue was on an earth foundation, it was necessary to underpin it before the excavation could be done. The building was supported on needles, and rubble masonry was put in from the bottom of the old foundation to the rock. The foundation of 413 West 31st Street, immediately west of the Express Building site, was

of very poor masonry, and it was necessary to rebuild it prior to taking out the adjoining excavation.

Along the north side, between Stations 186 + 50 and 187 + 50, the walls supporting the adjoining back yards were of poor quality and had to be renewed by the contractor before excavation could be done.

The excavated material was loaded by derricks on cars at the top of the excavation, these cars being on tracks having a direct connection with the disposal trestle, as shown by Fig. 1, Plate XXXVII. As soon as it could be done, derricks were placed at the bottom of the excavation; tracks were then laid out there, and the excavated material was loaded on cars at the bottom and hoisted by derricks to cars on the disposal trestle. A locomotive was lowered to the bottom of the excavation on August 25th, 1907, and a derrick started operating at the bottom on August 27th, 1907. The commencement of this work by derricks at the bottom is shown by Fig. 3, Plate XXXIX. In general, the disposal tracks were maintained about on the center line of 31st Street until the excavation had been carried as close to them as possible, and on October 16th, 1907, they were shifted to the extreme north side of the work, as shown by Fig. 2, Plate XXXVII. A portion of the old trestle was left in place near Tenth Avenue, a derrick was erected thereon, and the tracks were used for cars to receive the excavated material hoisted from sub-grade. The disposal trestle was maintained in this position until such time as it would interfere with the excavation, and then the tracks were abandoned. This was done on November 11th, 1908. Fig. 3, Plate XXXVII, shows the finishing of the excavation on the north side of the work. On August 30th, 1908, a cut was made under Ninth Avenue at sub-grade, and cars could then be run from Seventh to Tenth Avenue at sub-grade. On October 24th, 1908, the connection with the disposal trestle east of Ninth Avenue was abandoned, and all excavated material was hoisted from sub-grade at Tenth Avenue by derricks.

As previously stated, the contractor was required to make complete disposal of all excavated material after January 1st, 1909, but was allowed the use of the pier until January 20th, 1909, after which date the materials were hoisted by derricks at Tenth Avenue, loaded on 2-horse trucks, and transported to the 30th Street pier, North River, where it was loaded on scows by two electric derricks. A considerable amount of the rock excavation was broken up and used for back-fill.

PLATE XXXVII.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
CRESSON ON
TERMINAL STATION-WEST: PENNSYLVANIA RAILROAD.

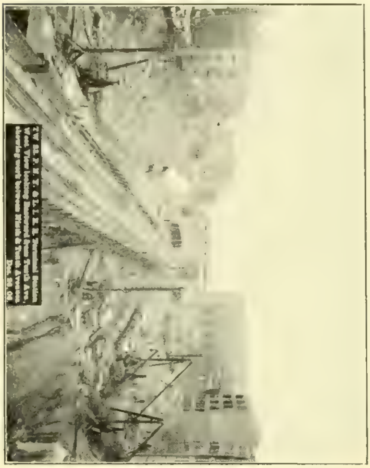


FIG. 1.

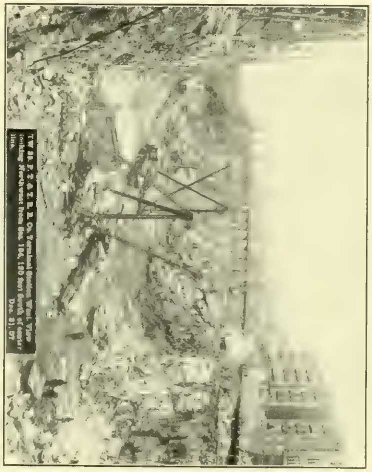


FIG. 2.

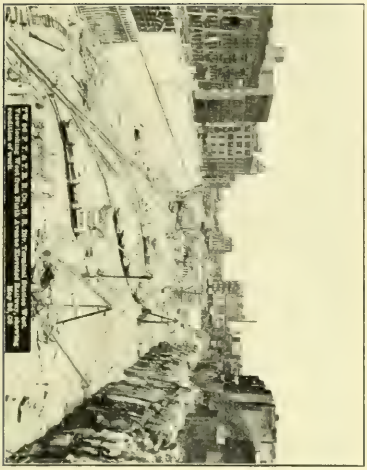


FIG. 3.

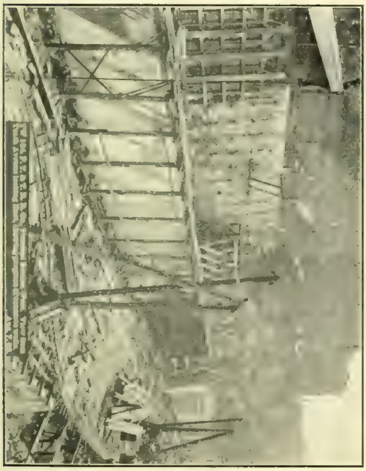


FIG. 4.

Earth Excavation.—Practically all the earth excavation, amounting to about 57 000 cu. yd., was done with steam shovels. The average quantity of earth excavated by a steam shovel per 10-hour shift was 180 cu. yd. This material was loaded on side-dump cars and taken to the disposal pier where it was dumped through chutes to the decks of scows. Inasmuch as the quantity of earth excavation was small, as compared with the rock, the earth was used principally for the first layer on the scows for padding, so that small stones might be dumped through the chutes without injuring the decks.

Rock Excavation.—As previously stated, the rock broke better on the south than on the north side, where there were several slides, and considerable excavation had to be taken out beyond the neat line required in the specifications. The worst slide occurred at midnight on July 3d, 1909, at about Station 188 + 50. The last blast, to complete the excavation to sub-grade at this point, had been fired in the afternoon of the same day, and the mucking was practically completed. Great care had been taken in excavating near this point, as it was evident that the rock was not of a very stable character, but, when the excavation had been completed, it was thought that the rock remaining in place would stand. The volume of material brought down by this slide amounted to about 200 cu. yd. The rock on the south side broke very well, and there were no slides of any consequence.

The drill holes were laid out by the blaster, and the general method of drilling for different classes of work was as follows: In breaking down, the holes were started about 8 ft. apart, on a slight batter, so that at the bottom they would be considerably less than 8 ft. apart. They were drilled about 10 ft. deep, and blasting logs were used, as it was necessary to load quite heavily in order to lift the material and start the cut. After the cut had been made, side holes were shot to widen out sufficiently to start another cut.

After a side cut about 20 ft. deep had been made, the side holes were drilled 20 ft. deep, and the holes were loaded and tamped for the full 20-ft. cut. Under the terms of the specifications, the contractor was required to complete the excavation on the sides by drilling broaching holes.

The maximum length of drill steel was about 20 ft., and, where the excavation plane of broaching was more than 20 ft. in depth, the contractor was permitted to start the holes back of the broaching line, in

order to allow for setting up the drills on the second lift. A distance of about 8 in. was usually allowed for setting up a drill. The broaching line was painted on the surface of the rock in advance of the drilling, and the batter of the drill was tested with a specially designed hand-level in which the bubble came to a central position when the face of the level was on the required batter. Holes were also drilled in front of this broaching line, and, when the excavation had been taken out to within about 6 ft. in front of it, the holes immediately in front were loaded, and also about every third one of the broaching holes, and, unless the rock was very bad, it usually broke sharply at the broaching line. Occasionally, the broaching holes which were not loaded were filled with sand, which gave rather better results than leaving them open.

In the steam-shovel work on the east side of Ninth Avenue, spring holes were used. They were formed by drilling a 20-ft. hole and exploding at the bottom of it, without tamping, two or three sticks of dynamite, and repeating this process with heavier charges until there had been formed at the bottom of the hole a large cavity which would hold from 100 to 200 lb. of dynamite. Face holes and breast holes were also drilled, and it was possible by this method to drill and break up a cut 20 ft. deep and 15 ft. thick. The only place where spring holes were used on this work was on the east side of Ninth Avenue, where the heavy cutting was sometimes extended beyond the east house line.

From the best records obtainable, the average progress in drilling was about 33 lin. ft. per 8-hour shift. The average number of cubic yards of excavation per drill shift was 13.9, and the average amount of drilling per cubic yard of excavation was 2.4 ft.; this covered more than 27 000 drill shifts.

The dynamite was practically all 60%, and the average excavation per pound of dynamite was 2.2 cu. yd. The contractor employed an inspector of batteries and fuses, who, using an instrument for that purpose, tested the wiring of each blast prior to firing, in order to discover any short circuits, and thus prevent the danger of leaving unexploded dynamite in the holes.

The average quantity of excavation per derrick shift of 10 hours, covering 7 400 shifts, 87% of the excavation being rock, was 50 cu. yd., and the average force per shift, including only foreman and laborers, was 13 men. It was found that a derrick operating at the top of a

20-ft. cut would handle about 40 cu. yd. per shift, whereas, if operating at the bottom of the cut, it would handle about 60 cu. yd. per shift. The elevator derricks at Tenth Avenue were very efficient, and each could take care of the material from four derricks at the bottom, hoisting 250 cu. yd. per shift a height of 60 ft.

Concrete Retaining and Face Walls.—It was essential to have the greatest space possible at the bottom of the excavation, and, inasmuch as the yard was to be left open, it was necessary to provide some facing for the rock on the sides in order to prevent disintegration,. due to exposure, and give a finished appearance to the work. Above the rock surface a retaining wall of gravity section was designed, the top being slightly higher than the yards of the adjoining properties. The face wall was designed to be as thin as possible, in order to allow the maximum space for tracks.

The excavation, therefore, was laid out so that the back of the retaining wall would not encroach on the adjoining property, but would practically coincide with the property line at positions of maximum depth.

The batter on the face of the wall was 2 in. per ft., and a bridge seat 3½ ft. wide was formed at an elevation of 22 ft., minimum clearance, above the top of the rail. This bridge seat was made level. The maximum height of the south wall is 49 ft., and of the north wall 65 ft.

The face walls were classed as "Upper Face Walls," extending from the base of the retaining wall to the bridge seat, and as "Lower Face Walls," extending from the bridge seat to the base of the wall. The general design is shown on Fig. 8.

In considering the design of the face wall it was felt that, the wall being so thin, ample provision should be made to prevent any accumulation of water and consequent pressure back of the wall; therefore, no attempt was made to water-proof it, but provision was made to carry off any water which might appear in the rock. Box drains, 2 ft. wide and 6 ft. from center to center, were placed against the rock, so that, there being but 4 ft. between the drains, and the wall having a minimum thickness of 2 ft., any water in the rock would not have to go more than 2 ft. to reach a drain, and would probably pass along the face of the rock to a drain rather than through 2 ft. of concrete. These drains were connected with pipes leading through the wall at its base.

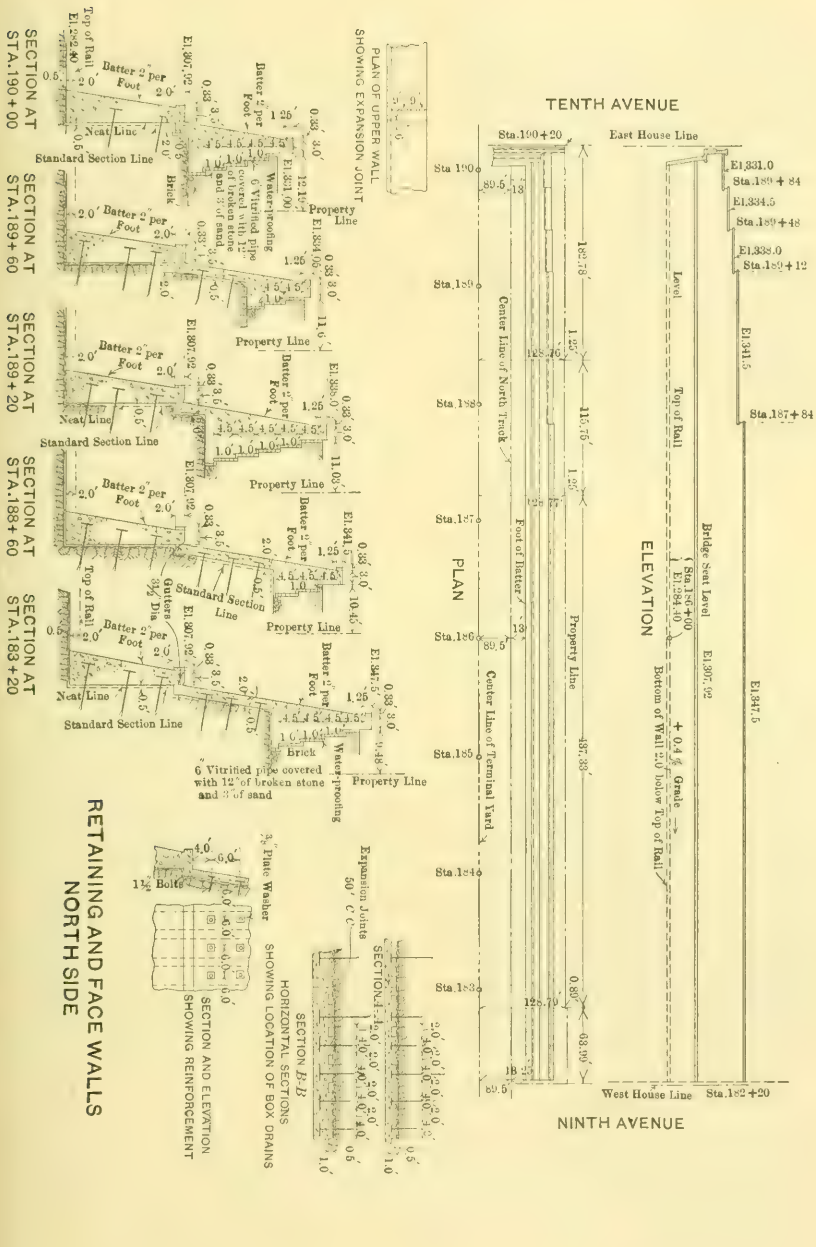
These box drains occurred so frequently, and decreased the section of the wall so materially, that it was thought desirable to tie the wall to the rock. This was done by drilling into the rock holes from 6 to 15 ft. in depth, and grouting into each hole a 1½-in. rod having a split end and a steel wedge. The outer end of each rod was fitted with a 12 by 12 by ½-in. plate and a nut, and extended into the wall, thus tying the concrete securely to the rock. The drains being 6 ft. from center to center, the tie-rods were placed midway between them, and 6 ft., from center to center, vertically and horizontally. Fig. 8 shows the arrangement of these rods and drains. Around the Express Building site, just west of Ninth Avenue, on the south side of the work, the bridge seat was omitted, and the face wall was designed 2 ft. thick from top to bottom. The batter on the 31st Street wall was made variable, the top and bottom being constant distances from the center line and on different grades.

The retaining walls were water-proofed with three layers of felt and coal-tar pitch, which was protected by 4 in. of brick masonry. A 6-in. vitrified drain pipe was laid along the back of the wall, with the joints open on the lower half, and this was covered with 1 ft. of broken stone and sand before any back-fill was placed on it.

The arrangement of the drains was as follows: The 6-in. drain back of the retaining wall was connected with one of the box drains in the rear of the face wall by a cast-iron pipe or wooden box every 24 ft., and this ran through the base of the retaining wall. Midway between these pipes, a connection was made at the bridge seat between the drain in the rear of the face wall and the gutter formed at the rear of the bridge seat to carry off rain-water coming down the face of the wall above. All the box drains, except those connected with the drains back of the retaining wall, were sealed at the elevation of the base of the retaining wall, as noted previously.

The specifications required vitrified pipe to be laid through the retaining wall, but, owing to the difficulty of holding the short lengths of pipe in place during the laying of wet concrete, they were dispensed with, and either iron pipes or wooden boxes were used.

Tie-Rods.—When the excavation on the sides had been completed, movable drilling platforms were erected, as shown by Fig. 4, Plate XXXVII. The holes were drilled on a pitch of 2 in. per ft. with the horizontal. The depths of the holes were decided by the engineer, and



RETAINING AND FACE WALLS NORTH SIDE

FIG. 8.

were on the basis of a minimum depth of 5 ft. in perfect rock; the character of the rock, therefore, and the presence of seams, determined the depths of the holes. Each hole was partly filled with grout, and the rod, with the steel wedge in the split end, was inserted and driven with a sledge so that the wedge, striking the bottom of the hole first, would cause the split end of the rod to open. Each hole was then entirely filled with neat cement grout.

Box Drains.—Various methods of forming the box drains were considered, such as using half-tile drains, or a metal form, or a collapsible form which could be withdrawn, but it was finally decided to build boxes in which the side toward the rock was open and the joints in the boxes and against the rock were plastered with cement mortar. These boxes were left in place. Fig. 1, Plate XXXVIII, shows the tie-rods and box drains in place, and holes being cut near the bottom of the drains for the pipes leading through the wall.

Forms.—Fig. 1, Plate XXXVIII, shows the form used on the south side of the work. The materials were of good quality, and the form, which was about 50 ft. long, was used to build twelve sections, or about 600 ft. of wall. The form was tied in at the top and bottom by cables attached to rods drilled into the rock, and it was thought that, with the trusses to stiffen the middle section of the form, it would not be necessary to use raker braces against it. This would be desirable, as the placing of the raker braces took considerable time. It was found, however, that the form was not sufficiently rigid, as it bulged at the middle section and could not be held by the trusses. Two or three sets of raker braces, about 12 ft. apart, were used, and in addition, rods with turnbuckles were placed through the form and fastened to the tie-rods, and thus the form was held in place successfully. On the forms built later, the trusses were omitted, and raker braces, about every 6 ft., were used. The rods which screwed into the turnbuckles were removed before the form was moved. The photograph, Fig. 4, Plate XXXIX, was taken inside the concrete form for the lower face wall on the north side, and shows the drains leading through the wall, the turnbuckles attached to the tie-rods, the cables attached to rods in the rock, and the braces to keep the form from coming in; these braces, of course, were removed as the concrete came up. The form was built low and wedged up into position. After a section of concrete had set sufficiently, the wedges were knocked out, the form was lowered and

PLATE XXXVIII.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
CRESSON ON
TERMINAL STATION-WEST: PENNSYLVANIA RAILROAD.

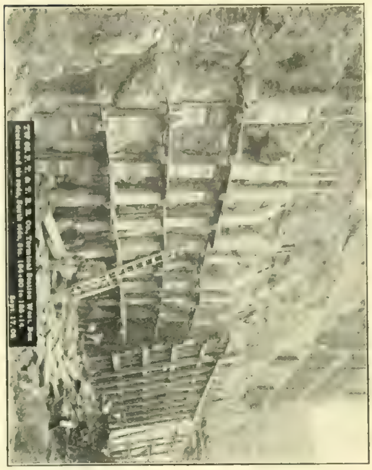


FIG. 1.

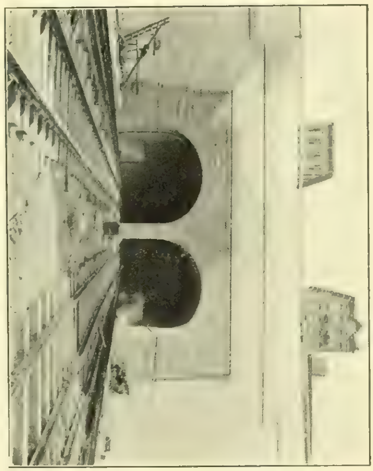


FIG. 2.

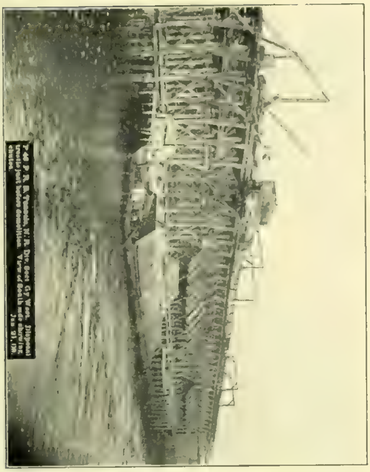


FIG. 3.

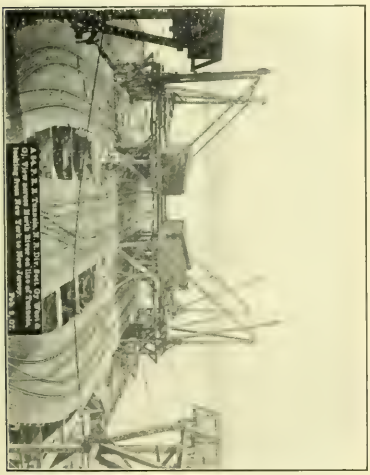


FIG. 4.

moved from the wall, and was then moved along the lowest waling piece by block and tackle to its new position.

Fig. 4, Plate XXXVII, shows the forms used on the north side of the work.

A section, 1 ft. square, at the top of the bridge seat of the lower face wall, was left out, so that the bottom of the form for the upper face wall could be braced against it. The top of this form was tied by cables attached to rods in the rock and by rods with turnbuckles running from back to front of the form; braces were also put in from the back of the retaining wall form to the walls of buildings along the property lines, when this could be done. The middle section of the form was held by rods with turnbuckles which passed through the form and were fastened to each of the tie-rods drilled into the rock, as was also done in the case of the lower face wall. It was generally possible to hold the form to true position in this manner, but occasionally it had a tendency to bulge; when this occurred, the rods leading through the form and fastened to the tie-rods were tightened up, the placing of the concrete was slowed up, and no serious bulging occurred.

Bulkheads at the ends of the sections were built of rough planking securely braced to the rock, except that a planed board was laid up against the face of the form to make a straight joint. At the end of each section a V was formed, as shown by Fig. 1, Plate XXXVIII. At all corners, a "return," or portion of the wall running at right angles, was built, and no section of wall was stopped at a corner.

Filling Forms of Lower Face Walls.—A temporary trestle was erected above the elevation of the bridge seat, and a track, leading from the mixer to the form to be filled, was laid on it. At the commencement of each section a layer of mortar (1 part of cement to $2\frac{1}{2}$ parts of sand) was deposited on the bottom. A 1 : 3 : 6 mixture of concrete was used; it was run from the mixer into dump-cars and deposited in the form through chutes, three of which were provided for each 50-ft. section, the average length. The concrete was mixed wet, and was not rammed; the stone was spaded back from the face, and no facing mixture or facing diaphragms were used. Work on each section was continued day and night without any intermission from the time of commencement to the time of completion. At frequent intervals the box drains were washed out thoroughly with a hose, in order to prevent them from clogging up with grout.

In the first few sections of wall, the form was filled to within 1 in. of the top of the bridge seat and allowed to set for about 2 hours; it was then finished to the proper elevation with a plaster of 1 part of cement to 1 part of sand. This did not prove satisfactory, as there were indications of checking and cracking, and, later, the form was filled to the required elevation and the surface floated. The form was allowed to remain in place for from 18 to 24 hours, depending on the weather. In most cases, immediately after the form had been moved, a scaffold was erected against the face of the wall, and the face was wet and thoroughly rubbed, first with a wooden float and then with a cement brick, until the surface was smooth and uniform.

The section 1 ft. square at the top of the bridge seat, which was left out in order to brace the bottom of the form for the upper face wall, was filled in after the walls had been completed. The old concrete was very thoroughly cleaned before the new concrete was placed on it, and a gutter was formed at the rear connecting with the box drains back of the wall to carry off rain-water coming down the face of the upper walls.

In hot weather the walls were thoroughly wetted down several times a day for several days after the form had been removed.

Upper Face and Retaining Wall.—In cases where the top of the retaining wall was at a higher elevation than the mixer, it was necessary to raise the concrete in a bucket with a derrick, and dump it into cars on the trestle above the top of the coping. Concrete was deposited through chutes, as in the lower face wall, continuously from the bottom of the face wall to the top of the retaining wall. At the commencement of each section of the retaining wall a layer of mortar was put on the rock. A 1 : 2 : 3 mixture of concrete was used in the face wall, and a 1 : 3 : 6 mixture in the retaining wall.

As the face walls were so thin, the number of batches of concrete per hour was reduced, for the form filled so rapidly that the concrete, before it set, exerted an excessive pressure against the form, and this tended to make it bulge. The proper rate at which to place the concrete behind a form 50 ft. long, with a wall 2 ft. thick, was found to be about fifteen ½-yd. batches per hour.

Cracks in Walls and Longitudinal Reinforcement.—Before the concrete walls were started, the contractor suggested using forms 100 ft.

PLATE XXXIX.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
CRESSON ON
TERMINAL STATION-WEST: PENNSYLVANIA RAILROAD.

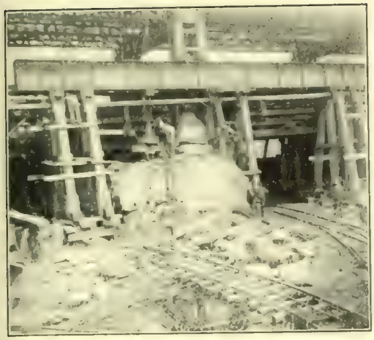


FIG. 1.—GIRDERS UNDER 9TH AVENUE ELEVATED RAILROAD.

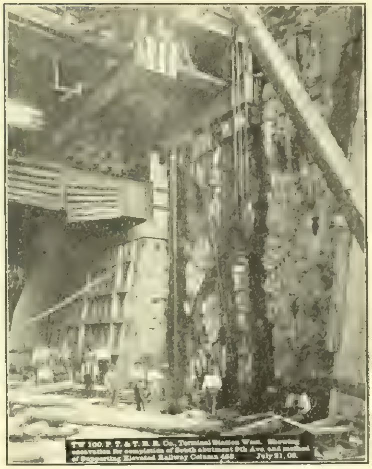


FIG. 2.

FIG. 3.

FIG. 4.

long and building the walls in sections of that length; it was decided, however, to limit the length to 50 ft.

The south walls, in sections approximately 50 ft. long, were built first, starting at Tenth Avenue and extending for about 500 ft. Soon after the forms were removed, irregular cracks appeared in the walls between the joints in practically every section. It was thought that these cracks might be due to the wall being very thin and being held at the back by the tie-rods, there was also quite a material change in the section of the wall at each drainage box. Although it was admitted that these cracks would have no effect on the stability of the wall, it was thought that, for appearance sake, it would be desirable to prevent or control them, if possible. The first method suggested was to shorten the sections to 25 ft., which would give an expansion and contraction joint every 25 ft., it being thought that sections of this length would not crack between the joints. This, however, was not considered desirable. An effort was then made to prevent cracks in a section of wall, about 46 ft. long, on the south side, by using longitudinal reinforcement. In the lower and upper face walls, $\frac{3}{4}$-in. square twisted steel rods were placed longitudinally about 4 in. in from the face and about 1 ft. 4 in. apart vertically. The sections of these walls were finished on April 10th, and May 5th, 1909, respectively. At present there are no indications of cracks in these sections, and they are practically the only ones in the south walls which do not show irregular cracks.

It was decided, however, that, inasmuch as the cracks did not affect the stability of the walls, the increased cost of thus reinforcing the remaining walls was not warranted. An effort to control the cracks was made by placing corrugated-iron diaphragms in the form, dividing each 50-ft. section into three parts. The diaphragms were 1 ft. wide, and were placed with the outer edge 1 in. in from the face of the wall, but in the copings they were omitted. The purpose of these diaphragms was to provide weak sections in the walls, so that if there was any tendency to crack it would occur along the line of the diaphragms. Corrugated iron was used for the diaphragms instead of sheet iron as it was more easily maintained in a vertical position. The general arrangement of the diaphragms is shown on Fig. 4, Plate XXXIX. The results obtained by using diaphragms have been quite satisfactory, and cracks approximately straight and vertical have usually appeared

opposite the diaphragms soon after the forms were removed. Diaphragms were used on all the remaining walls, with the exception of those between Stations 187 + 07 and 188 + 83 on the north side, where the rock was of poor character and bad slides had occurred. Between these points, in order to strengthen the wall, twisted steel rods, 1 in. square, were placed longitudinally, 6 in. in from the face of the wall and 2 ft. apart vertically, between Elevations 295 and 335.

Tenth Avenue Portal.—The design of the Tenth Avenue Portal is shown on Fig. 9. The stone selected came from the Millstone Granite Company's Quarries, Millstone Point, Conn., and is a close-grained granite. Fig. 2, Plate XXXVIII, shows the completed portal.

Practically all the stone cutting was done at the quarry, but certain stones in each course were sent long and were cut on the ground, in order to make proper closures. Drains were left behind the portal around the back of each arch, leading down to the bottom, and through the concrete base at each side of the portal and in the central core-wall; all these drains have been discharging water.

Power-House.—The old church at No. 236 West 34th Street, between Seventh and Eighth Avenues, was turned over to the New York Contracting Company-Pennsylvania Terminal for a power-house to supply compressed air for use on the Terminal Station work between Seventh and Ninth Avenues and the work below sub-grade as well as that on the Terminal Station-West. Four straight-line compressors and one cross-compound Corliss compressor were installed, the steam being supplied by three Stirling boilers. Three electrically-driven air compressors, using current at 6 600 volts, were also installed, and the total capacity of the power-house was about 19 000 cu. ft. of free air per minute compressed to 90 lb. per sq. in.

Disposal Pier.—The disposal pier (old No. 62 and new No. 72), at the foot of West 32d Street, North River, was leased by the Pennsylvania Railroad Company. The entire pier, with the exception of the piles, was taken down, and the piles which would be in the path of the proposed tunnel were withdrawn prior to the building of the tunnels and the construction of the pier for disposal purposes. Subsequent to the driving of the tunnels there was a considerable settlement in the pier, especially noticeable at the telphers, and finally these had to be abandoned on this account. Fig. 3, Plate XXXVIII, shows the chutes through which the earth was dumped on the decks of the scows

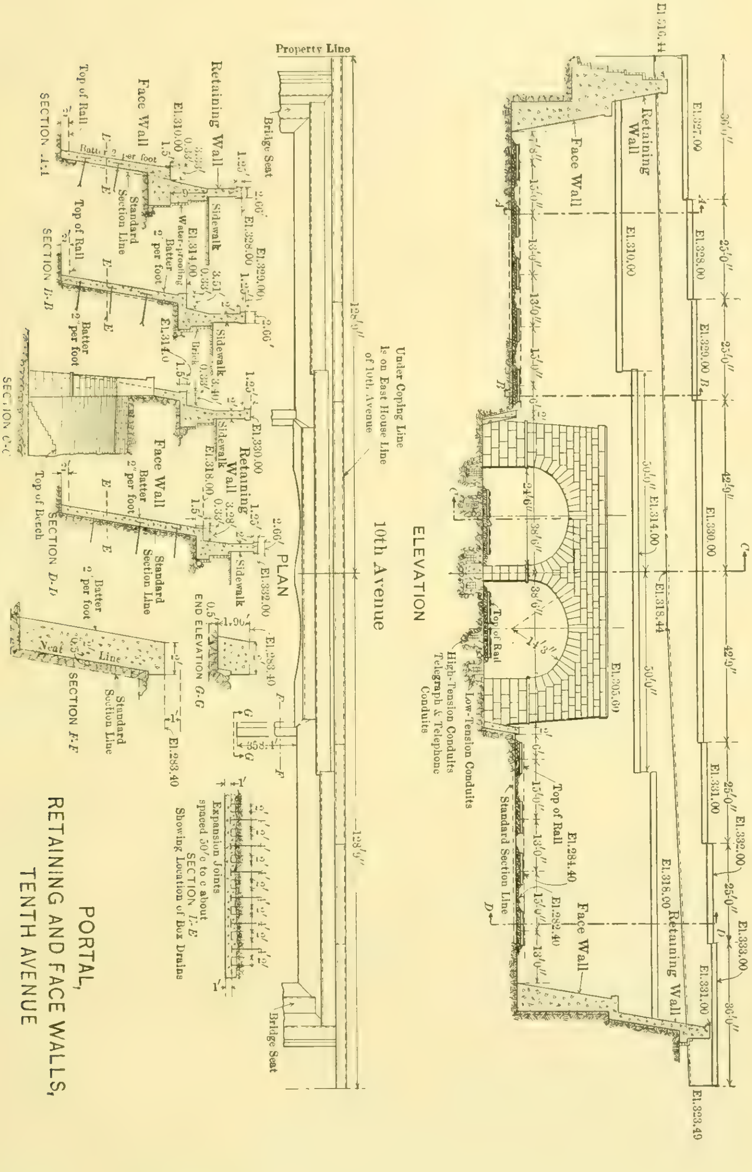


FIG. 9.

PORTAL, RETAINING AND FACE WALLS, TENTH AVENUE

to form a padding on which to dump the heavier rock. Fig. 4, Plate XXXVIII, shows the derricks at the end of the pier. These were used, not only for loading heavy stones and skips, but also with a clam-shell bucket for bringing in broken stone and sand for use in the work. Large quantities of pipe, conduits, brick, etc., were also brought to this pier for use on the work.

Organization of Engineering Force in Field.

The design and execution of the work were under the direction of Charles M. Jacobs, M. Am. Soc. C. E., Chief Engineer, and James Forgie, M. Am. Soc. C. E., Chief Assistant Engineer. The writer acted as Resident Engineer.

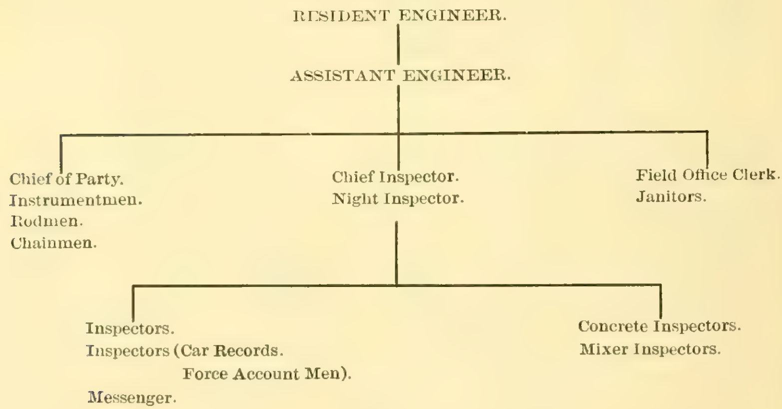


Fig. 10.

The general organization of the engineering force in the field is shown by the diagram, Fig. 10.

The position of Assistant Engineer, in responsible charge of Construction and Records, has been filled in turn by Messrs. A. W. Gill, N. C. McNeil, Jun. Am. Soc. C. E., and W. S. Greene, Assoc. M. Am. Soc. C. E.

Messrs. A. P. Combes and T. B. Brogan have acted as Chief Inspector and Night Inspector, respectively, in charge of outside work during the entire carrying out of the contract.

Base lines had been established on Ninth and Tenth Avenues for the Terminal work east of Ninth Avenue and for the Tunnel work

west of Tenth Avenue, and these lines, together with bench-marks similarly established, were used in laying out the Terminal Station-West work.

Prior to the commencement of the work, elevations were taken on the surface at 10-ft. intervals, and elevations of the rock surface were taken on these points as the rock was uncovered. Cross-sections were made and used in computing the progress and final estimates.

Very careful records were kept of labor, materials, derrick performances, steam-shovel performances, quantity of dynamite used, etc., and, in addition, a diary was kept giving a description of the work and materials used each day; various tables and diagrams were also prepared.

A daily report was sent to the Chief Office showing the quantities of excavation removed and concrete built, the force in the field, the plant at work, etc., during the previous day. At the end of each month a description of the work done during that month, with quantities, force of men employed, percentages of work done, etc., was sent to the Chief Office. Two diagrams, showing cross-sections and contours of the excavation done and the progress of the concrete walls, were also sent.

Cost Account.

From the records of labor and material obtained in the field, and from estimated charges for administration and power, an estimate was made of the cost to the contractor for doing various classes of work. It was necessary to estimate the administration and power charges, as the contractor's organization and power-house were also controlling and supplying power to the Terminal Station work east of Ninth Avenue and also the work below sub-grade. The labor and material charges in the field were placed directly against the class of work on which they were used and the administration and general charges (which included superintendence, lighting, etc.) were apportioned to the various classes of work in proportion to the value of the labor done.

Statistics.

The total weight of the structural steel used during the underpinning of Ninth Avenue was 1 475 000 lb.

The total weight supported during the work under Ninth Avenue was about 5 000 tons.

The average daily traffic over the Ninth Avenue Elevated Railway was 90 000 passengers, and, during the progress of the excavation and underpinning, about 100 000 000 passengers were carried over that structure.

The total excavation was 521 000 cu. yd., of which 87% was solid rock.

The average drill performance was about 33 lin. ft. per 8-hour shift.

The average number of cubic yards of excavation per drill shift was 13.9.

The average number of feet of drilling per cubic yard of excavation was about 2.4.

The average excavation per pound of dynamite was 2.2 cu. yd.

The average amount of excavation per derrick shift of ten hours, 87% of the excavation being rock, was 50 cu. yd.

The average derrick force per shift, including only foreman and laborers, was 13 men.

The salaries of the engineering staff in the field and the expenses of equipping and maintaining the field office amounted to 2.8% of the cost of the work executed, 2.7% being for engineering salaries alone.

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PAPERS AND DISCUSSIONS

TESTS OF CREOSOTED TIMBER.*

By W. B. Gregory, Esq.†

During the last few years a quantity of literature has appeared in which the treatment of timber by preservatives has been discussed. The properties of timber, both treated and untreated, have been determined by the Forest Service, United States Department of Agriculture, and through its researches valuable knowledge has come to engineers who have to deal with the design of wooden structures. There is very little information, however, regarding the effect of time on creosoted timber, and for this reason the results given herewith may prove of interest.

The material tested consisted of southern pine stringers having a cross-section approximately 6 by 16 in. and a length of 30 ft. For the purpose of testing, each beam was cut into two parts, each about 15 ft. long. This material had been in use in a trestle of a railroad near New Orleans for 26 years. The stringers were chosen at random to determine the general condition of the trestle. The timber had been exposed to the weather and subjected to heavy train service from the time it was treated until it was tested. The annual rainfall at New Orleans is about 60 in., and the humidity of the air is high. In spite of these conditions, there was no appearance of decay on any of the

* This paper will not be presented at any meeting, but written communications on the subject are invited for publication with it in *Transactions*.

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specimens tested. The specifications under which the timber was treated were as follows:

TIMBER.

The timber for creosoting shall be long-leafed or southern pine. Sap surfaces on two or more sides are preferred.

Piles.—The piles shall be of long-leafed or southern pine, not less than 14 in. at the butt. They shall be free from defects impairing their strength, and shall be reasonably straight.

The piles shall be cleanly peeled, no inner skin being left on them. The oil used shall be so-called creosote oil, from London, England, and shall be of a heavy quality.

The treatment will vary according to the dimensions of the timbers and length of time they have been cut. Timbers of large and small dimensions shall not be treated in the same charge, neither shall timbers of differing stages of air seasoning, or the close-grained, be treated in the same charge with coarse or open-grained timbers.

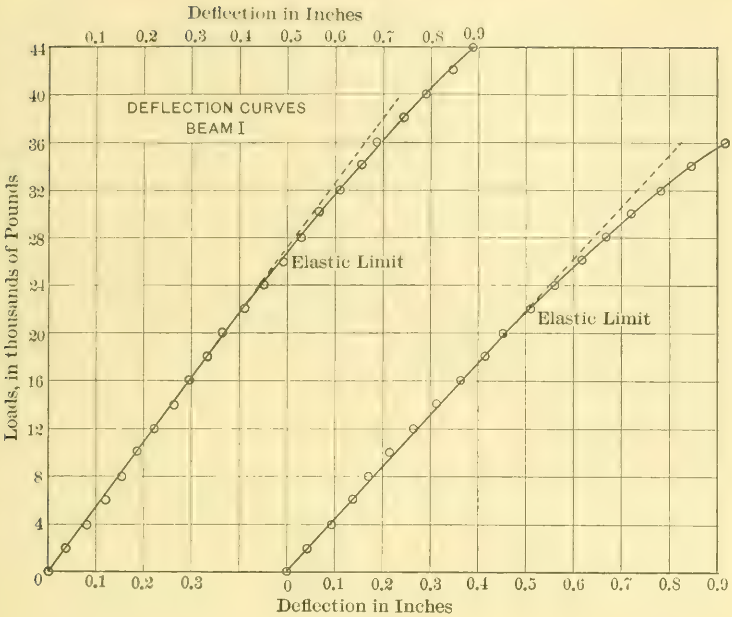
The timbers shall be subjected first to live steam superheated to from 250 to 275° Fahr., and under a 30 to 40-lb. pressure. The live steam shall be admitted into the cylinders through perforated steam pipes, and the temperature shall be obtained by using superheated steam in closed pipes in the cylinders.

The length of time this steaming shall last will depend on the size of the timbers and the length of time they have been cut. In piles and large timbers freshly cut, as long a time as 12 hours may be required. After the steaming is accomplished, the live steam shall be shut off and the superheated steam shall be maintained at a temperature of 160° or more and a vacuum of from 20 to 25 in. shall be held for 4 hours or longer, if the discharge from the pumps indicates the necessity.

Oil Treatment.—The temperature being maintained at 160° Fahr., the cylinders shall be promptly filled with creosote oil at a temperature as high as practicable (about 100° Fahr.). The oil shall be maintained at a pressure ranging from 100 to 120 lb., as experience and measurements must determine the length of time the oil treatment shall continue, so that the required amount of oil may be injected.

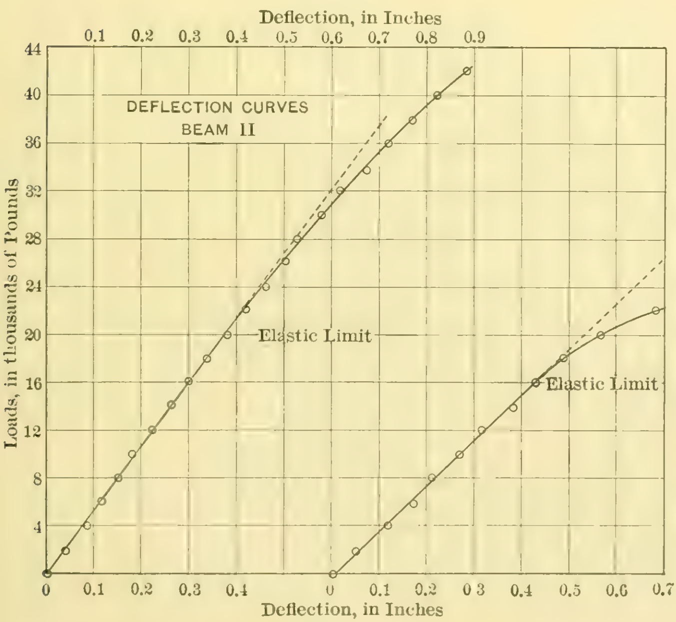
After the required amount of oil is injected, the superheated steam shall be shut off, the oil let out, the cylinders promptly opened at each end, and the timber immediately removed from the cylinder.

In the erection of timbers the sap side must be turned up, and framing or cutting of timbers shall not be permitted, if avoidable. All cut surfaces of timbers shall be saturated with hot asphaltum, thinned with creosote oil. The heads of piles when cut shall be promptly coated with the hot asphaltum and oil, even though the cut-off be temporary.



Deflection in Inches
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
DEFLECTION CURVES
BEAM I
Elastic Limit
Elastic Limit
Loads, in thousands of Pounds
0 4 8 12 16 20 24 28 32 36 40 44
0 0.1 0.2 0.3
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Deflection in Inches

FIG. 1.



Deflection, in Inches
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
DEFLECTION CURVES
BEAM II
Elastic Limit
Elastic Limit
Loads, in thousands of Pounds
4 8 12 16 20 24 28 32 36 40 44
0 0.1 0.2 0.3 0.4
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
Deflection, in Inches

FIG. 2.

Method of Testing.

The tests were made on a Riehlé 100 000-lb. machine in the Experimental Engineering Laboratory of Tulane University of Louisiana. The machine is provided with a cast-iron beam for cross-bending tests. The distance between supports was 12 ft. The method of support was as follows: Each end of the beam was provided with a steel roller which rested on the cast-iron beam of the testing machine, while above the roller, and, directly under the beam tested, there was a steel plate 6 by 8 in. in area and 1 in. thick. The area was sufficiently great to distribute the load and prevent the shearing of the fibers of the wood. The head of the Riehlé machine is 10 in. wide. A plate, ⅝ in. thick, 6 in. wide and 18 in. long, was placed between the head of the machine and the beam tested.

TABLE 1.—Summary of Results of Transverse Tests of Beams at Tulane University, February 10th to March 2d, 1909.

Number of beam.	Top or butt of log.	b	h	I	Loads:		$S = \frac{P\,l\,c}{4\,I}$		d, Inches.	E	Weight, in pounds per cubic foot.	Remarks.
		Width, in inches.	Height, in inches.	$I = \frac{b\,h^3}{12}$	Actual at elastic limit.	Maximum.	At elastic limit.	Maximum.	At elastic limit.	$E = \frac{P\,l^3}{48\,d\,I}$		
I	B	6.28	15.94	2 120	22 000	45 900	2 975	6 200	0.41	1 575 000	50.2	Close-grained pine,
I	T	6.00	15.69	1 934	20 000	38 000	2 915	5 540	0.465	1 383 000	47.5	long-leaf.
II*	T	6.37	15.81	2 098	20 000	43 450	2 722	5 918	0.380	1 562 000	40.5	Coarse loblolly,
II	B	6.41	16.41	2 360	16 000	25 040	1 999	3 130	0.430	979 000	42.2	large knots.
III	T	5.88	15.63	1 871	24 000	45 130	3 608	6 785	0.535	1 489 000	40.4	Close-grained, long-leaf, no
III	B	5.88	15.90	1 965	21 000	35 190	3 054	5 120	0.515	1 288 000	44.2	knots.
IV	T	6.00	15.43	1 835	22 000	38 425	3 320	5 810	0.465	1 601 000	40.8	Loblolly, with
IV	B	6.12	15.87	2 032	22 000	35 500	3 090	4 983	0.660	1 017 000	41.5	knots.
V	B	6.00	16.00	2 048	22 000	47 000	3 090	6 610	0.400	1 670 000	47.2	Long-leaf yellow
V*	T	6.00	15.87	1 999	14 000	22 050	1 998	3 145	0.315	1 382 000	42.1	pine.
VI*	B	5.50	15.75	1 790	22 000	51 330	3 484	8 925	0.450	1 695 000	50.2	Long-leaf yellow
VI*	T	5.87	15.62	1 865	20 000	44 000	3 013	6 627	0.410	1 625 000	45.2	pine.
VII	B	6.56	15.62	2 083	34 000	51 900	4 589	6 985	0.620	1 637 000	43.7	Long-leaf yellow
VII*	T	6.22	15.62	1 975	20 000	49 000	2 845	6 970	0.380	1 658 000	40.2	pine.

* Failed in longitudinal shear.

The deflection was measured on both sides of each beam by using silk threads stretched on each side from nails driven about 2 in. above the bottom of the beam and directly over the rollers which formed the supports. From a small piece of wood, tacked to the bottom of the

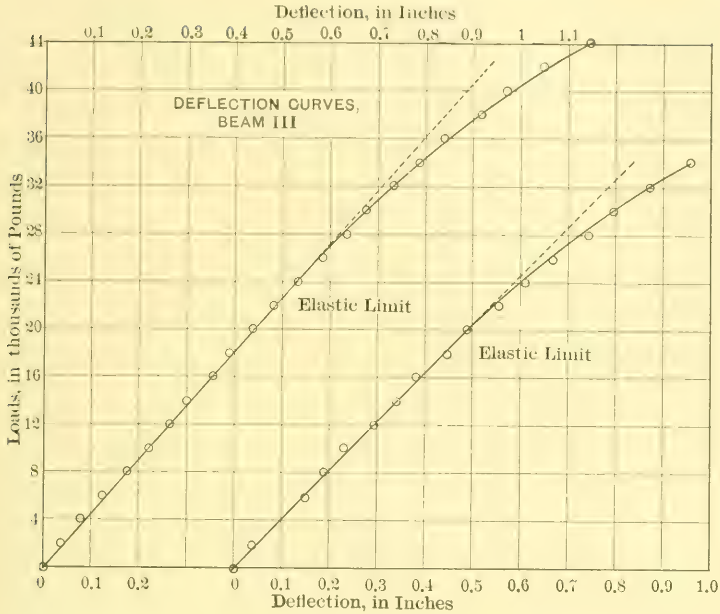

Deflection, in Inches
DEFLECTION CURVES,
BEAM III
Elastic Limit
Elastic Limit
Loads, in thousands of Pounds
Deflection, in Inches

FIG. 3.

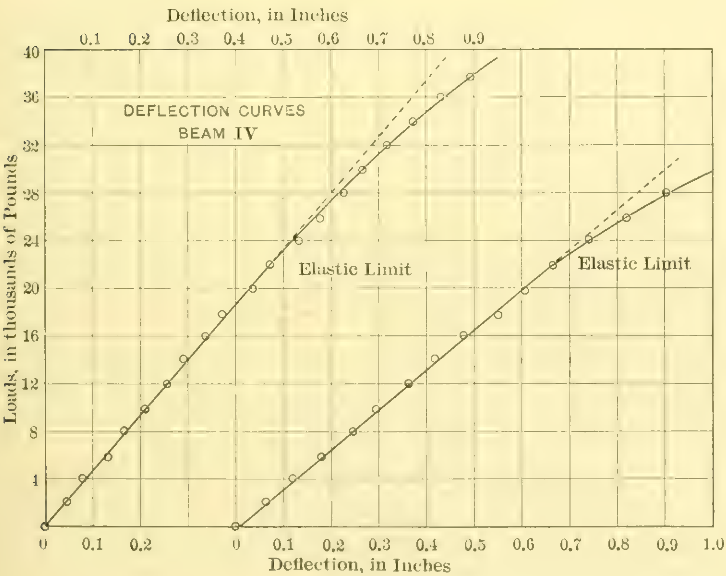

Deflection, in Inches
DEFLECTION CURVES
BEAM IV
Elastic Limit
Elastic Limit
Loads, in thousands of Pounds
Deflection, in Inches

FIG. 4.

beam at its center and projecting at the sides, the distance to these threads was measured. These measurements were taken to the nearest hundredth of an inch. The mean of the deflections was taken as the true deflection for any load.

In computing the various quantities shown in Table 1, the summary of results, the load has been assumed as concentrated at the center of the beam. While it is true that the load was spread over a length of about 12 in., due to the width of the head of the machine and the plate between it and the beam tested, it is also true that there were irregularities, such as bolt-holes and, in some cases, abrasions due to wear, that could not well be taken into account. Hence, it was deemed sufficiently accurate to consider the load as concentrated. Besides the horizontal bolt-holes, shown in the photographs, there were vertical bolt-holes, at intervals in all the beams. The latter were $\frac{7}{8}$ in. in diameter, and in every case they were sufficiently removed from the center of the length of the beam to allow the maximum moment at the reduced section to be relatively less than that at the center of the beam. For this reason, no correction was made for these holes. The broken beams often showed that rupture started at, or was influenced by, some of the holes, especially the horizontal ones.

While some of the heavy oils of a tarry consistency remained, they were only to be found in the sappy portions of the long-leaf pine and in the loblolly (Specimens II and IV). Exposure in a semi-tropical climate for 26 years had resulted in the removal of the more volatile portions of the creosote oil. The penetration of the oil into the sap wood seemed to be perfect, while in the loblolly it varied from a fraction of an inch to $1\frac{1}{2}$ in. In the heart wood there was very little penetration across the grain. The timber had been framed and the holes bored before treatment. The penetration of the creosote along the grain from the holes was often from 4 to 6 in.

Circular 39 of the Forest Service, U. S. Department of Agriculture, entitled "Experiments on the Strength of Treated Timber," gives the results of a great many tests of creosoted ties, principally loblolly pine, from which the following conclusions are quoted:

"(1) A high degree of steaming is injurious to wood. The degree of steaming at which pronounced harm results will depend upon the quality of the wood and its degree of seasoning, and upon the pressure (temperature) of steam and the duration of its application. For

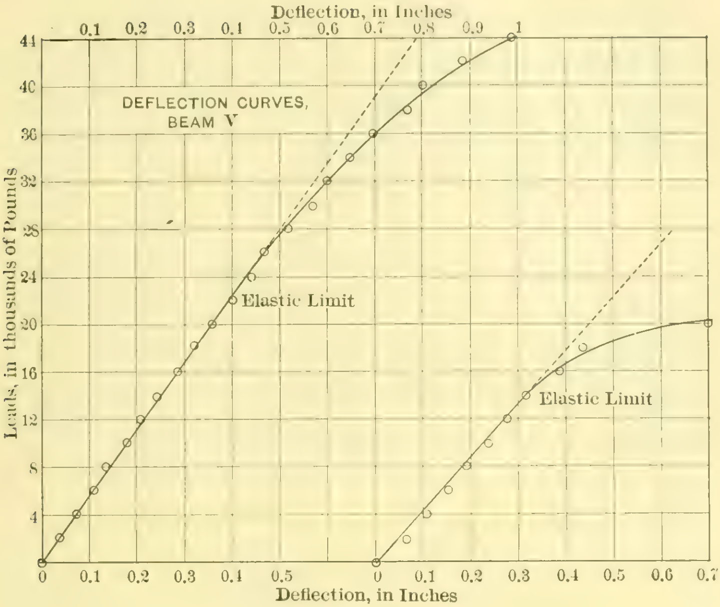

Deflection, in Inches
DEFLECTION CURVES, BEAM V
Elastic Limit
Elastic Limit
Loads, in thousands of Pounds
Deflection, in Inches

FIG. 5.

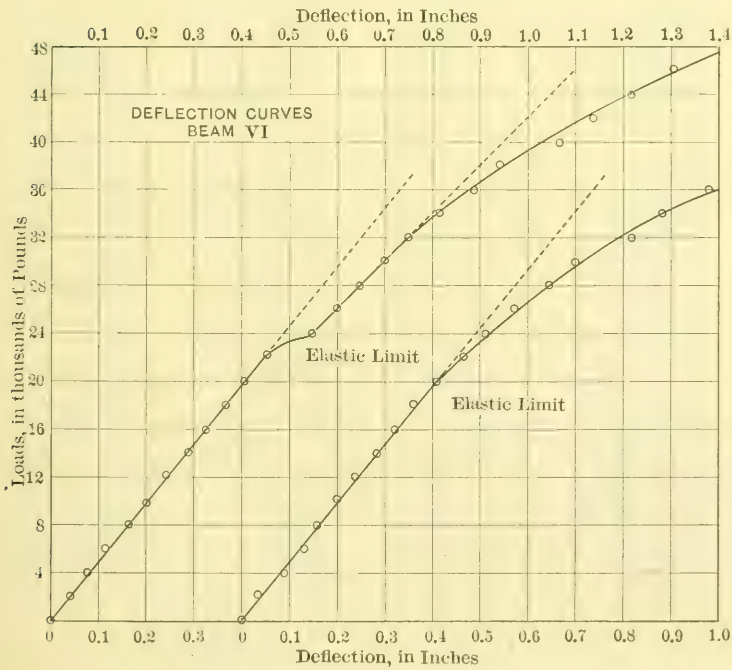

Deflection, in Inches
DEFLECTION CURVES BEAM VI
Elastic Limit
Elastic Limit
Loads, in thousands of Pounds
Deflection, in Inches

FIG. 6.

loblolly pine the limit of safety is certainly 30 pounds for 4 hours, or 20 pounds for 6 hours." [Tables 3, 6, and 7.]

"(2) The presence of zinc chlorid will not weaken wood under static loading, although the indications are that the wood becomes brittle under impact." [Tables 3 and 4.]

"(3) The presence of creosote will not weaken wood of itself. Since apparently it is present only in the openings of the cells, and does not get into the cell walls, its action can only be to retard the seasoning of the wood." [Tables 3, 4, 5, and 6.]

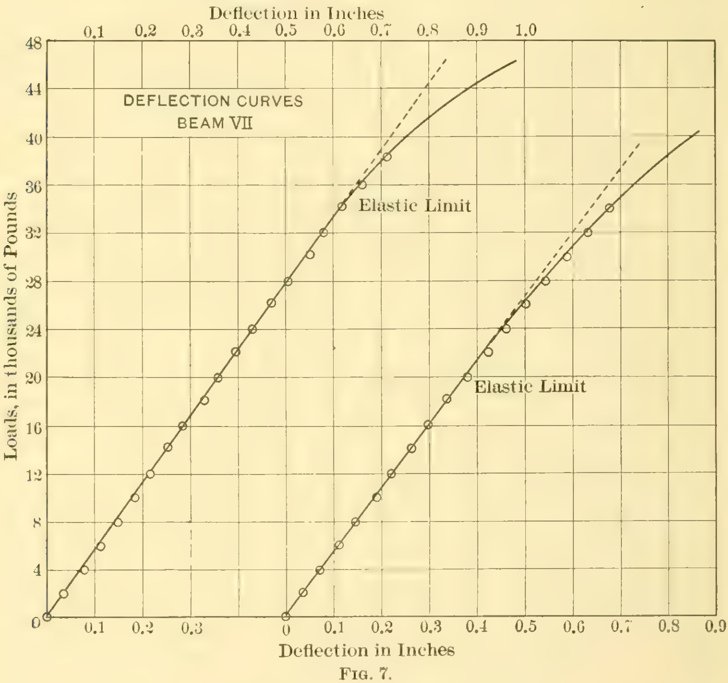


FIG. 7.

COMPARISONS.

A comparison of the results obtained with tests made on untreated timber is interesting, and to this end Tables 2 and 3, from Circular 115, Forest Service, U. S. Department of Agriculture, by W. Kendrick Hatt, Assoc. M. Am. Soc. C. E., are quoted. The tests made by the writer were from timber raised in Louisiana and Mississippi, while the tests quoted were from timber raised farther north. The number of tests was not sufficient to settle questions of average strength or other qualities. It will be seen, however, that the treated timber 26 years old compares favorably with the new untreated timber.

Fig. 1.—Specimen in Testing Machine, Showing Method of Support.

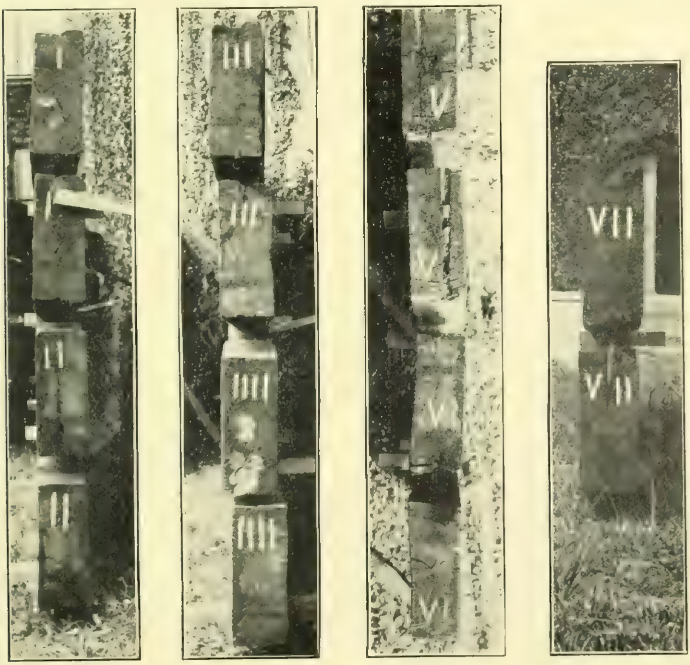


Fig. 2.—End Views of Tested Timbers.

TABLE 2.—Bending Strength of Large Sticks.

Loblolly Pine.

Reference number.	Locality of growth.	Dimensions. Section, in inches.	Dimensions. Span, in feet.	Grade.	Condition of seasoning.		Number of tests.	Moisture, per cent.	Rings per inch.	Specific gravity, dry.	Weight per Cubic Foot, in Pounds. As tested.	Weight per Cubic Foot, in Pounds. Oven dry.	Fiber stress at elastic limit, in pounds per square inch.	Modulus of rupture, in pounds per square inch.	Modulus of elasticity, in thousands of pounds per square inch.	Elastic resilience, in inch-pounds per cubic inch.	Number tailing by longitudinal shear.	Remarks.
1	South Carolina.	6 by 7 6 by 10 4 by 12 6 by 16 8 by 14 8 by 16	10 to 15.5	Square edge....	Green ...	Average...	42	48.0	5.7	0.50	46.2	31.2	3 150	5 580	1 426	0.45	7	Moisture above saturation point in all cases.
						Maximum.		92.1	11.7	0.60	56.8	37.5	5 210	8 460	1 920	0.99		
						Minimum..		30.2	2.3	0.40	35.6	25.0	1 675	3 120	905	0.07		
2	South Carolina.	6 by 7 4 by 12 6 by 10 6 by 16 8 by 16 10 by 16	10 to 16	Square edge....	Partially air dry.	Average...	18	27.7	5.0	0.50	40.0	31.2	3 380	5 650	1 435	0.45	0	Moisture from 25 to 30 per cent.
						Maximum.		29.2	8.2	0.55	43.7	34.4	4 610	8 090	1 880	0.76		
						Minimum..		25.5	2.5	0.45	35.6	28.1	2 115	3 600	1 152	0.20		
3	South Carolina.	6 by 7 4 by 12 6 by 10 6 by 16	10 to 15	Square edge....	Partially air dry.	Average...	19	21.0	5.6	0.50	37.5	31.2	2 970	5 690	1 340	0.39	2	Moisture less than 25 per cent.
						Maximum.		24.9	17.2	0.58	45.6	36.2	4 850	8 100	2 040	0.69		
						Minimum..		15.9	2.7	0.41	31.2	25.6	1 730	2 910	906	0.10		
4	Virginia...	8 by 8	6 to 16	Square edge....	Partially air dry.	Average...	12	22.4	4.8	0.46	35.6	28.8	3 260	5 180	1 180	0.51	0	
						Maximum.		27.7	8.8	0.58	43.1	36.2	5 300	8 950	1 728	1.05		
						Minimum..		17.8	2.5	0.37	30.0	23.1	1 280	2 180	606	0.13		
5	Virginia...	8 by 8	6 to 15.5	Square edge....	Green....	Average...	17	64.0	3.0	0.43	43.7	26.9	1 935	3 490	744	0.31	0	Very rapid growth; poor quality.
						Maximum.		100.5	4.0	0.51	51.9	31.9	3 185	4 720	1 193	0.78		
						Minimum..		33.8	2.5	0.35	35.0	21.9	956	2 180	357	0.12		

Long-Leaf Pine.

Reference number.	Locality of growth.	Section, in inches.	Span, in feet.	Grade.	Condition of seasoning.		Number of tests.	Moisture, per cent.	Rings per inch.	Specific gravity, dry.	As tested.	Oven dry.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Elastic resilience.	Number tailing by longitudinal shear.	Remarks.
6	South Carolina.	6 by 8 10 by 16	15	Merchantable	Partially air dry.	Average...	22	25.0	13.7	0.58	45.6	36.2	3 800	7 160	1 560	0.53	9	
						Maximum.		40.3	25.4	0.76	60.0	47.5	4 970	10 020	2 010	0.78		
						Minimum..		17.3	6.2	0.50	39.4	31.2	2 220	5 450	1 190	0.21		
7	Georgia ...	10 by 12	15	Merchantable	Partially air dry.	Average...	22	27.3	18.0	0.69	54.7	42.9	5 581	8 384	1 820	......	6	Excellent merchantable grade.
						Maximum.		34.5	29.0	0.79	.....	49.4	9 600	11 410	2 920	......		
						Minimum..		20.0	11.0	0.50	.....	31.4	3 547	4 836	1 167	......		

TABLE 3.—LOBLOLLY PINE.—BENDING TESTS ON BEAMS SEASONED UNDER DIFFERENT CONDITIONS.

(8 by 16-in. section ; $13\frac{1}{2}$ to 15-ft. span.)

	Number of tests.	Fiber stress at elastic limit, in pounds per square inch.	Modulus of rupture, in pounds per square inch.	Longitudinal shear at maximum load, in pounds per square inch.	Modulus of elasticity, in thousands of pounds per square inch.	Percentage of moisture.	Rings per inch.	Weight per cubic foot, oven dry, in pounds.	Condition of seasoning.
Average	4	3 580	5 480	364_4	1 780	23.2	9.4	33.7	Air dry, 3½ months in the open.
Maximum		4 070	6 600	440	1 987	24.3	11.5	34.5	
Minimum		3 090	5 000	327	1 530	21.5	8.0	32.5	
Average	5	4 512	5 060	333_3	1 685	20	7.7	33.9	Kiln dry, 6 days.
Maximum		5 840	7 320	488	1 790	22	10.2	38.0	
Minimum		3 180	2 150	143	1 410	18	4.7	27.7	
Average	12	4 331	6 721	493_9	1 688	......	7.7	......	Air dry, 21 months under shelter.
Maximum		4 990	8 560	620	2 002	......	9.5	......	
Minimum		3 110	5 160	380	1 398	......	5.5	......	

NOTE.—Figures written as subscripts to the figures for longitudinal shear indicate the number of sticks failing in that manner.

SIDE VIEWS OF TESTED TIMBERS.

TABLE 4.—Load and Deflection Log. Beam I.

Date: February 26th, 1909.

$l = 12$ ft.; b (mean) $= 6\frac{3}{32}$ in.; h (mean) $= 15\frac{15}{16}$ in.; $c = 7.97$ in. Time $= 1$ hour.

No.	P Load, in pounds.	Deflection, in Inches. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.86	0	1.88	0	0
2	2 000	1.92	0.05	1.90	0.02	0.035
3	4 000	1.96	0.10	1.94	0.06	0.080
4	6 000	1.99	0.13	1.98	0.10	0.115
5	8 000	2.03	0.17	2.02	0.14	0.155
6	10 000	2.05	0.19	2.06	0.18	0.185
7	12 000	2.10	0.24	2.09	0.21	0.225
8	14 000	2.13	0.27	2.13	0.25	0.260
9	16 000	2.17	0.31	2.16	0.28	0.295
10	18 000	2.20	0.34	2.20	0.32	0.330
11	20 000	2.24	0.36	2.25	0.37	0.365
12	22 000	2.28	0.42	2.28	0.40	0.410
13	24 000	2.32	0.46	2.32	0.44	0.450
14	26 000	2.36	0.50	2.36	0.48	0.490
15	28 000	2.40	0.54	2.39	0.51	0.525
16	30 000	2.43	0.57	2.44	0.56	0.565
17	32 000	2.48	0.62	2.48	0.60	0.610
18	34 000	2.52	0.66	2.53	0.65	0.655
19	36 000	2.56	0.70	2.56	0.68	0.690
20	38 000	2.61	0.75	2.62	0.74	0.745
21	40 000	2.65	0.79	2.67	0.79	0.790
22	42 000	2.70	0.84	2.73	0.85	0.845
23	44 000	2.75	0.89	2.77	0.89	0.890

37 500 lb., First Crack; 45 900 lb., Failed.

At Elastic Limit: Load, 22 000 lb.; deflection, 0.41 in.; S, 2 975 lb.
Maximum: Load, 45 900 lb.; deflection, ...; S, 6 209 lb.
$E = 1\,575\,000$ lb.

Date: February 24th, 1909.

$l = 12$ ft.; b (mean) $= 6$ in.; h (mean) $= 15.69$ in.; $c = 7.84$ in.

P Load, in pounds.	Deflection, in Inches. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
0	1.83	0	1.86	0	0
2 000	1.87	0.04	1.90	0.04	0.04
4 000	1.91	0.08	1.96	0.10	0.090
6 000	1.96	0.13	2.00	0.14	0.135
8 000	2.00	0.17	2.04	0.18	0.175
10 000	2.04	0.21	2.08	0.22	0.215
12 000	2.09	0.26	2.13	0.27	0.265
14 000	2.14	0.31	2.18	0.32	0.315
16 000	2.19	0.36	2.23	0.37	0.365
18 000	2.24	0.41	2.28	0.42	0.415
20 000	2.29	0.46	2.33	0.47	0.465
22 000	2.34	0.51	2.39	0.53	0.520
24 000	2.39	0.56	2.43	0.57	0.565
26 000	2.44	0.61	2.48	0.62	0.615
28 000	2.49	0.66	2.53	0.67	0.665
30 000	2.55	0.72	2.58	0.72	0.720
32 000	2.61	0.78	2.65	0.79	0.785
34 000*	2.68	0.85	2.70	0.84	0.845
36 000	2.74	0.91	2.78	0.92	0.915
38 000			Broke.		

At Elastic Limit: Load, 20 000 lb.; deflection, 0.465 in.; S, 2 975 lb.
Maximum: Load, 38 000 lb.; deflection ......; S, 5 540 lb.
$E = 1\,383\,000$ lb.

* First crack.

TABLE 4.—(*Continued.*)—LOAD AND DEFLECTION LOG. BEAM II.

Date: February 20th, 1909.	Date: ....
l = 12 ft.; b (mean) = 6.38 in.; h (mean) = 15.81 in.; c = 7.91 in. Time = 47.5 min.	l = 12 ft.; b (mean) = 6.41 in.; h (mean) = 16.41 in.; c = 8.20 in.

No.	P	Deflection, in Inches.					P	Deflection, in Inches.				
	Load, in pounds.	Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.	Load, in pounds.	Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.65	0	1.68	0	0	0	1.86	0	1.87	0	0
2	2 000	1.69	0.04	1.72	0.04	0.040	2 000	1.91	0.05	1.92	0.05	0.05
3	4 000	1.73	0.08	1.77	0.09	0.085	4 000	1.98	0.12	1.98	0.11	0.115
4	6 000	1.76	0.11	1.80	0.12	0.115	6 000	2.05	0.19	2.02	0.15	0.170
5	8 000	1.80	0.15	1.83	0.15	0.150	8 000	2.07	0.21	2.08	0.21	0.210
6	10 000	1.83	0.18	1.86	0.18	0.180	10 000	2.13	0.27	2.13	0.26	0.265
7	12 000	1.87	0.22	1.90	0.22	0.220	12 000	2.18	0.32	2.18	0.31	0.315
8	14 000	1.91	0.26	1.94	0.26	0.260	14 000	2.25	0.39	2.24	0.37	0.380
9	16 000	1.95	0.30	1.98	0.30	0.300	16 000	2.30	0.44	2.29	0.42	0.430
10	18 000	1.98	0.33	2.02	0.34	0.335	18 000*	2.35	0.49	2.35	0.48	0.485
11	20 000	2.03	0.38	2.06	0.38	0.380	20 000	2.44	0.58	2.42	0.55	0.565
12	22 000	2.07	0.42	2.10	0.42	0.420	22 000	2.54	0.68	2.54	0.67	0.675
13	24 000	2.11	0.46	2.14	0.46	0.460	25 040			Failed.		
14	26 000	2.15	0.50	2.18	0.50	0.500						
15	28 000	2.18	0.53	2.22	0.54	0.535						
16	30 000	2.23	0.58	2.26	0.58	0.580						
17	32 000	2.27	0.62	2.30	0.62	0.620						
18	34 000	2.32	0.67	2.35	0.67	0.670						
19	36 000	2.37	0.72	2.40	0.72	0.720						
20	38 000	2.42	0.77	2.45	0.77	0.770						
21	40 000	2.48	0.83	2.50	0.82	0.825						
22	42 000	2.53	0.88	2.56	0.88	0.880						
23	43 450			Fracture.								
24	45 710			Failed.								

At Elastic Limit: Load, 20 000 lb.; deflection, 0.38 in.; S, 2 722 lb.
Maximum: Load, 43 450 lb.; deflection, ...; S, 5 918 lb.
E = 1 562 000 lb.

At Elastic Limit: Load, 16 000 lb.; deflection, 0.43 in.; S, 1 999 lb.
Maximum: Load, 25 040 lb.; deflection, ...; S, 3 130 lb.
E = 979 000 lb.

* First crack.

TABLE 4.—(*Continued.*)—Load and Deflection Log. Beam III.

Date: February 13th, 1909.

$l = 12$ ft.; b (mean) $= 5.88$ in.;
h (mean) $= 15.63$ in.;
$c = 7.82$ in.

No.	*P* Load, in pounds.	Deflection, in Inches. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.23	0	1.06	0	0
2	2 000	1.27	0.04	1.10	0.04	0.040
3	4 000	1.32	0.09	1.13	0.07	0.080
4	6 000	1.37	0.14	1.17	0.11	0.125
5	8 000	1.42	0.19	1.22	0 16	0.175
6	10 000	1.47	0.24	1.26	0.20	0.220
7	12 000	1.51	0.28	1.31	0.25	0.265
8	14 000	1.55	0.32	1.35	0.29	0.305
9	16 000	1.60	0.37	1.40	0.34	0.355
10	18 000	1.64	0.41	1.44	0.38	0.395
11	20 000	1.68	0.45	1.49	0.43	0.440
12	22 000	1.72	0.49	1.54	0.48	0.485
13	24 000	1.78	0.55	1.58	0.52	0.535
14	26 000	1.82	0.59	1.64	0.58	0.585
15	28 000	1.88	0.65	1.68	0.62	0.635
16	30 000	1.92	0.69	1.73	0.67	0.680
17	32 000	1.97	0.74	1.79	0.73	0.735
18	34 000	2.02	0.79	1.85	0.79	0.790
19	36 000	2.07	0.84	1.90	0.84	0.840
20	38 000	2.13	0.90	1.97	0.91	0.915
21	40 000	2.20	0.97	2.03	0.97	0.970
22	42 000	2.27	1.04	2.11	1.05	1.045
23	44 000	2.37	1.14	2.21	1.15	1.145

39 100 lb. First Crack; 45 130 lb. Failed.

At Elastic Limit: Load, 24 000 lb.; deflection, 0.535 in.; S, 3 608 lb.
Maximum: Load, 45 130 lb.; deflection, ...; S, 6 785 lb.

$E = 1\,489\,000$ lb.

Date: ....

$l = 12$ ft.; b (mean) $= 5.88$ in.;
h (mean) $= 15.9$ in.;
$c = 7.95$ in. Time $= 45$ min.

P Load, in pounds.	Deflection, in Inches. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
0	1.67	0	1.63	0	0
2 000	1.70	0.03	1.68	0.05	0.040
4 000	1.72	0.05	1.72	0.09	0.070
6 000	1.82	0.15	1.78	0.15	0.150
8 000	1.86	0.19	1.82	0.19	0.190
10 000	1.90	0.23	1.87	0.24	0.235
12 000	1.97	0.30	1.92	0.29	0.295
14 000	2.00	0.33	1.98	0.35	0.340
16 000	2.03	0.36	2.04	0.41	0.385
18 000	2.10	0.43	2.09	0.46	0.445
20 000	2.13	0.46	2.14	0.51	0.485
22 000	2.20	0.53	2.20	0.57	0.550
24 000	2.26	0.59	2.26	0.63	0.610
26 000	2.31	0.64	2.32	0.69	0.665
28 000	2.38	0.71	2.40	0.77	0.740
30 000	2.42	0.75	2.47	0.84	0.795
32 000	2.49	0.82	2.55	0.92	0.870
34 000	2.58	0.91	2.62	0.99	0.950

22 000 lb. First Crack; 35 190 lb. Failed.

At Elastic Limit: Load, 21 000 lb.; deflection, 0.515 in.; S, 3 054 lb.
Maximum: Load, 35 190 lb.; deflection, ...; S, 5 120 lb.

$E = 1\,288\,000$ lb.

TABLE 4.—(*Continued.*)—LOAD AND DEFLECTION LOG. BEAM IV.

Date: February 16th, 1909.

l = 12 ft.; b (mean) = 6.0 in.; h (mean) = 15.43 in.; c = 7.71 in.

No.	P Load, in pounds.	Deflection, in Inches. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	2.28	0	2.05	0	0
2	2 000	2.31	0.03	2.10	0.05	0.040
3	4 000	2.34	0.06	2.14	0.09	0.075
4	6 000	2.40	0.12	2.19	0.14	0.130
5	8 000	2.43	0.15	2.23	0.18	0.165
6	10 000	2.47	0.19	2.28	0.23	0.210
7	12 000	2.51	0.23	2.32	0.27	0.250
8	14 000	2.54	0.26	2.37	0.32	0.290
9	16 000	2.59	0.31	2.41	0.36	0.335
10	18 000	2.62	0.34	2.45	0.40	0.370
11	20 000	2.68	0.40	2.50	0.45	0.425
12	22 000	2.72	0.44	2.54	0.49	0.465
13	24 000	2.78	0.50	2.60	0.55	0.525
14	26 000	2.82	0.54	2.65	0.60	0.570
15	28 000	2.87	0.59	2.69	0.64	0.615
16	30 000	2.91	0.63	2.74	0.69	0.660
17	32 000	2.97	0.69	2.78	0.73	0.710
18	34 000	3.01	0.73	2.85	0.80	0.765
19	36 000	3.07	0.79	2.90	0.85	0.820
20	38 000	3.14	0.86	2.98	0.93	0.895

34 000 lb. First Crack; 38 425 lb. Failed.

At Elastic Limit: Load, 22 000 lb.; deflection, 0.465 in.; S, 3 320 lb.
Maximum: Load. 38 425 lb.; deflection, ...; S, 5 810 lb.
E = 1 601 000 lb.

Date: February 10th, 1909.

l = 12 ft.; b (mean) = 6.12 in.; h (mean) = 15.87 in.; c = 7.93 in. Time = 30 min.

No.	P Load, in pounds.	Deflection, in Inches. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.44	0	1.58	0	0
2	2 000	1.50	0.06	1.64	0.06	0.06
3	4 000	1.55	0.11	1.70	0.12	0.115
4	6 000	1.62	0.18	1.76	0.18	0.180
5	8 000	1.68	0.24	1.82	0.24	0.240
6	10 000	1.72	0.28	1.89	0.31	0.295
7	12 000	1.80	0.36	1.94	0.36	0.360
8	14 000	1.85	0.41	2.00	0.42	0.415
9	16 000	1.90	0.46	2.06	0.48	0.470
10	18 000	1.98	0.54	2.13	0.55	0.545
11	20 000	2.03	0.59	2.19	0.61	0.600
12	22 000	2.09	0.65	2.25	0.67	0.660
13	24 000	2.15	0.71	2.33	0.75	0.730
14	26 000	2.23	0.79	2.42	0.84	0.815
15	28 000	2.32	0.88	2.49	0.91	0.895
16	30 000	2.42	0.98	2.62	1.04	1.010
17	32 000	2.56	1.12	2.74	1.16	1.140
18	34 000	2.67	1.23	2.87	1.29	1.265

28 360 lb. Cracked; 35 500 lb. Failed.

At Elastic Limit: Load, 22 000 lb.; deflection, 0.66 in.; S, 3 090 lb.
Maximum: Load. 35 500 lb.; deflection, ...; S, 4 983 lb.
E = 1 017 000 lb.

TABLE 4.—(*Continued.*)—LOAD AND DEFLECTION LOG. BEAM V.

Date:	Date: February 27th, 1909.
$l = 12$ ft.; b (mean) $= 6$ in.; h (mean) $= 16$ in. $c = 8$ in. Time $= 40$ min.	$l = 12$ ft.; b (mean) $= 6$ in.; h (mean) $= 15.87$ in.; $c = 7.94$ in.

No.	*P* Load, in pounds.	DEFLECTION, IN INCHES. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.	*P* Load, in pounds.	DEFLECTION, IN INCHES. Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.97	0	1.37	0	0	0	1.31	0	1.25	0	0
2	2 000	2.01	0.04	1.40	0.03	0.035	2 000	1.37	0.06	1.31	0.06	0.06
3	4 000	2.06	0.09	1.43	0.06	0.075	4 000	1.41	0.10	1.36	0.11	0.105
4	6 000	2.08	0.11	1.47	0.10	0.105	6 000	1.46	0.15	1.40	0.15	0.150
5	8 000	2.11	0.14	1.50	0.13	0.135	8 000	1.49	0.18	1.45	0.20	0.190
6	10 000	2.16	0.19	1.54	0.17	0.180	10 000	1.54	0.23	1.49	0.24	0.235
7	12 000	2.19	0.22	1.57	0.20	0.210	12 000	1.58	0.27	1.53	0.28	0.275
8	14 000	2.22	0.25	1.61	0.24	0.245	14 000	1.62	0.31	1.57	0.32	0.315
9	16 000	2.25	0.28	1.65	0.28	0.280	16 000	1.68	0.37	1.65	0.40	0.385
10	18 000	2.29	0.32	1.69	0.32	0.320	18 000	1.73	0.41	1.71	0.46	0.435
11	20 000	2.32	0.35	1.73	0.36	0.355	20 000	1.99	0.68	1.97	0.72	0.700
12	22 000	2.36	0.39	1.78	0.41	0.400						
13	24 000	2.39	0.42	1.83	0.46	0.440						
14	26 000	2.42	0.45	1.85	0.48	0.465						
15	28 000	2.47	0.50	1.90	0.53	0.515						
16	30 000	2.50	0.53	1.95	0.58	0.565						
17	32 000	2.54	0.57	1.99	0.62	0.595						
18	34 000	2.59	0.62	2.04	0.67	0.645						
19	36 000	2.63	0.66	2.09	0.72	0.690						
20	38 000	2.68	0.71	2.17	0.80	0.755						
21	40 000	2.73	0.76	2.21	0.84	0.800						
22	42 000	2.80	0.83	2.30	0.93	0.880						
23	44 000	2.90	0.93	2.40	1.03	0.980						

25 000 lb. Slight Crack; 47 000 lb. Failed.

At Elastic Limit: Load, 22 000 lb.; deflection, 0.40 in.; *S*, 3 090 lb.
Maximum: Load, 47 000 lb.; deflection, ...; *S*, 6 610 lb.

$E = 1\,670\,000$ lb.

20 000 lb. First Crack; 22 050 lb. Failed.

At Elastic Limit: Load, 14 000 lb.; deflection, 0.315 in.; *S*, 1 998 lb.
Maximum: Load, 22 050 lb.; deflection, ...; *S*, 3 145 lb.

$E = 1\,382\,000$ lb.

TABLE 4.—(*Continued.*)—LOAD AND DEFLECTION LOG. BEAM VI.

	Date: February 12th, 1909. l = 12 ft.; b (mean) = 5.5 in.; h (mean) = 15.75 in.; c = 7.88 in. Time = 40 min.						Date: February 13th, 1909. l = 12 ft.; b (mean) = 5.87 in.; h (mean) = 15.62 in.; c = 7.81 in.					
	P	DEFLECTION, IN INCHES.					P	DEFLECTION, IN INCHES.				
No.	Load, in pounds.	Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.	Load, in pounds.	Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.22	0	1.30	0	0	0	1.28	0	1.30	0	0
2	2 000	1.26	0.04	1.34	0.04	0.04	2 000	1.30	0.02	1.35	0.05	0.035
3	4 000	1.29	0.07	1.38	0.08	0.075	4 000	1.36	0.08	1.39	0.09	0.085
4	6 000	1.33	0.11	1.42	0.12	0.115	6 000	1.40	0.12	1.44	0.14	0.130
5	8 000	1.37	0.15	1.47	0.17	0.160	8 000	1.43	0.15	1.47	0.17	0.160
6	10 000	1.42	0.20	1.51	0.21	0.205	10 000	1.47	0.19	1.51	0.21	0.200
7	12 000	1.45	0.23	1.55	0.25	0.240	12 000	1.51	0.23	1.56	0.26	0.245
8	14 000	1.50	0.28	1.59	0.29	0.285	14 000	1.55	0.27	1.60	0.30	0.285
9	16 000	1.54	0.32	1.63	0.33	0.325	16 000	1.59	0.31	1.64	0.34	0.325
10	18 000	1.58	0.36	1.68	0.38	0.370	18 000	1.62	0.34	1.69	0.39	0.365
11	20 000	1.61	0.39	1.72	0.42	0.405	20 000	1.66	0.38	1.74	0.44	0.410
12	22 000	1.66	0.44	1.76	0.46	0.450	22 000	1.71	0.43	1.80	0.50	0.465
13	24 000	1.81	0.59	1.81	0.51	0.550	24 000	1.77	0.49	1.84	0.54	0.515
14	26 000	1.86	0.64	1.86	0.56	0.600	26 000	1.83	0.55	1.90	0.60	0.575
15	28 000	1.91	0.69	1.91	0.61	0.650	28 000	1.90	0.62	1.97	0.67	0.645
16	30 000	1.96	0.74	1.96	0.66	0.700	30 000	1.97	0.69	2.02	0.72	0.705
17	32 000	2.00	0.78	2.02	0.72	0.750	32 000	2.12	0.84	2.10	0.80	0.820
18	34 000	2.04	0.82	2.11	0.81	0.815	34 000	2.20	0.92	2.16	0.86	0.885
19	36 000	2.10	0.88	2.20	0.90	0.890	36 000	2.29	1.01	2.24	0.94	0.975
20	38 000	2.16	0.94	2.25	0.95	0.945	38 000	2.39	1.11	2.32	1.02	1.065
21	40 000	2.28	1.06	2.38	1.08	1.070						
22	42 000	2.38	1.16	2.42	1.12	1.140						
23	44 000	2.44	1.22	2.52	1.22	1.220						
24	46 000	2.53	1.31	2.60	1.30	1.305						
25	48 000	2.66	1.44	2.71	1.41	1.425						
26	50 000	2.78	1.56	2.87	1.57	1.565						

33 000 lb. First Crack; 51 330 lb. Failed.
At Elastic Limit: Load, 22 000 lb.; deflection, 0.45 in.; S, 3 484 lb.
Maximum: Load, 51 330 lb.; deflection, ...; S, 8 925 lb.
E = 1 695 000 lb.

24 000 lb., First Crack; 44 000 lb., Failed.
At Elastic Limit: Load, 20 000 lb.; deflection, 0.41 in.; S, 3 013 lb.
Maximum: Load, 44 000 lb.; deflection, ...; S, 6 627 lb.
E = 1 625 000 lb.

TABLE 4.—(*Continued.*)—LOAD AND DEFLECTION LOG. BEAM VII.

	Date: March 2d, 1909. l = 12 ft.; b (mean) = 6.56 in.; h (mean) = 15.62 in.; c = 7.81 in. Time = 1 hr.						Date: February 20th, 1909. l = 12 ft.; b (mean) = 6.22 in.; h (mean) = 15.62 in.; c = 7.81 in. Time = 33 min.					
	P	Deflection, in Inches.					P	Deflection, in Inches.				
No.	Load, in pounds.	Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.	Load, in pounds.	Reading.	Total deflection.	Reading.	Total deflection.	Mean total deflection.
1	0	1.84	0	1.71	0	0	0	1.69	0	1.73	0	0
2	2 000	1.88	0.04	1.74	0.03	0.035	2 000	1.72	0.03	1.77	0.04	0.035
3	4 000	1.92	0.08	1.79	0.08	0.080	4 000	1.76	0.07	1.80	0.07	0.070
4	6 000	1.96	0.12	1.81	0.10	0.110	6 000	1.80	0.11	1.84	0.11	0.110
5	8 000	2.00	0.16	1.85	0.14	0.150	8 000	1.84	0.15	1.87	0.14	0.145
6	10 000	2.03	0.19	1.89	0.18	0.185	10 000	1.88	0.19	1.92	0.19	0.190
7	12 000	2.06	0.22	1.93	0.22	0.220	12 000	1.91	0.22	1.95	0.22	0.220
8	14 000	2.11	0.27	1.95	0.24	0.255	14 000	1.95	0.26	2.00	0.27	0.265
9	16 000	2.14	0.30	1.99	0.28	0.290	16 600	1.99	0.30	2.03	0.30	0.300
10	18 000	2.18	0.34	2.03	0.32	0.330	18 000	2.03	0.34	2.06	0.33	0.335
11	20 000	2.22	0.38	2.05	0.34	0.360	20 000	2.07	0.38	2.11	0.38	0.380
12	22 000	2.25	0.41	2.10	0.39	0.400	22 000	2.11	0.42	2.16	0.43	0.425
13	24 000	2.29	0.45	2.13	0.42	0.435	24 000	2.15	0.46	2.20	0.47	0.465
14	26 000	2.32	0.48	2.17	0.46	0.470	26 000	2.19	0.50	2.24	0.51	0.505
15	28 000	2.36	0.52	2.21	0.50	0.510	28 000	2.23	0.54	2.28	0.55	0.545
16	30 000	2.40	0.56	2.25	0.54	0.550	30 000	2.27	0.58	2.33	0.60	0.590
17	32 000	2.43	0.59	2.29	0.58	0.585	32 000	2.32	0.63	2.37	0.64	0.635
18	34 000	2.47	0.63	2.32	0.61	0.620	34 000	2.36	0.67	2.42	0.69	0.680
19	36 000	2.51	0.67	2.37	0.66	0.665	36 000					
20	38 000	2.56	0.72	2.41	0.70	0.710						

27 000 lb., First Crack; 51 900 lb., Failed.

At Elastic Limit: Load, 34 000 lb.; deflection, 0.62 in.; S, 4 580 lb.
Maximum: Load, 51 900 lb.; deflection, ...; S, 6 985 lb.

E = 1 637 000 lb.

28 000 lb., First Crack; 49 000 lb., Failed.

At Elastic Limit: Load, 20 000 lb.; deflection, 0.38 in.; S, 2 845 lb.
Maximum: Load, 49 000 lb.; deflection, ...; S, 6 970 lb.

E = 1 658 000 lb.

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PAPERS AND DISCUSSIONS

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD: THE BERGEN HILL TUNNELS.

By F. Lavis, M. Am. Soc. C. E.

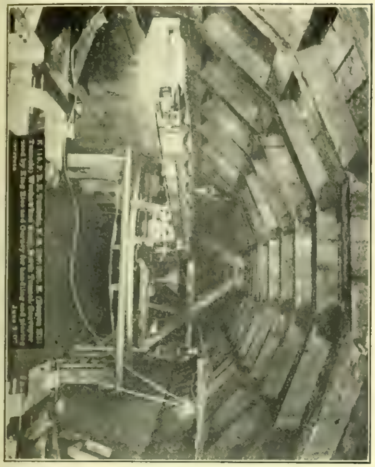
To be Presented April 6th, 1910.

Location.—That section of the Pennsylvania Railroad's New York Tunnels lying west of the Hudson River is designated Section "K," and the tunnels are generally spoken of as the Bergen Hill Tunnels. Bergen Hill is a trap dike (diabase) forming the lower extension of the Hudson River Palisades.

There are two parallel single-track tunnels, cross-sections of which are shown on Plate XXXII of the paper by Charles M. Jacobs, M. Am. Soc. C. E. The center line is a tangent, and nearly on the line of 32d Street, New York City, produced, its course being N. 50° 30′ W. The elevation of the top of the rail at the Weehawken Shaft (a view of which is shown by Fig. 2, Plate XLIII), on the west bank of the Hudson River, is about 64 ft. below mean high water; and at the Western Portal, or Hackensack end, the rail is about 17 ft. above; the grade throughout is 1.3%, ascending from east to west. The length of each tunnel between the portals is 5 920 ft.

A general plan and profile of these tunnels is shown on Plate LVIII of the paper by Charles W. Raymond, M. Am. Soc. C. E. At

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.



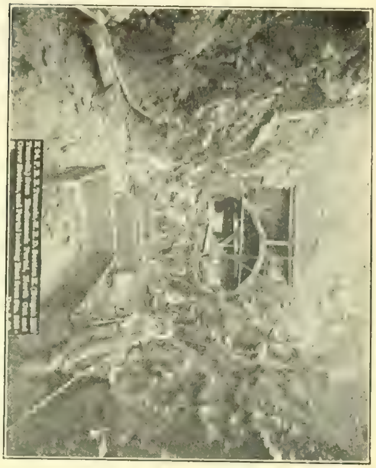
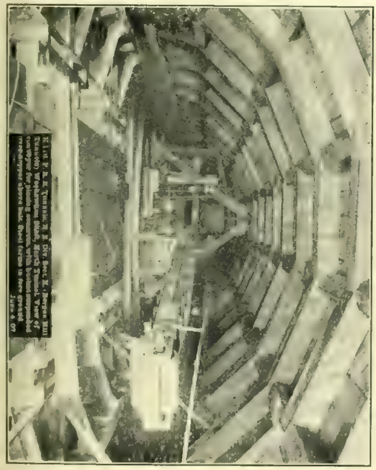


FIG. 1.



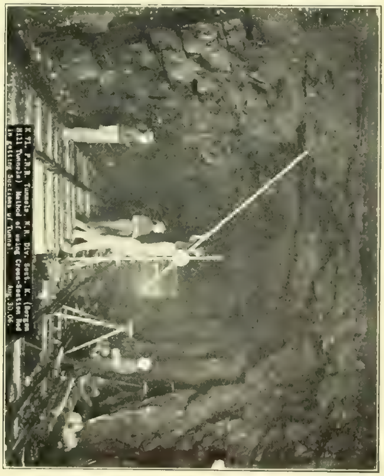


FIG. 2.

Central Avenue a shaft 212 ft. deep was sunk. It is 3 620 ft. from the Weehawken Shaft.

History.—The contract for this work was let on March 6th, 1905, to the John Shields Construction Company; it was abandoned by the Receiver for that company on January 20th, 1906, and on March 20th, of that year, was relet to William Bradley, who completed the work by December 31st, 1908.

The progress of excavation and lining in the North Tunnel is shown graphically on the progress diagram, Fig. 9, that of the South Tunnel being practically the same.

Geology.—Starting west from the Weehawken Shaft, the tunnels pass through a wide fault for a distance of nearly 400 ft., this fault being a continuation of that which forms the valley between the detached mass of trap and sandstone known as King's Bluff, which lies north of the tunnels, and the main trap ridge of Bergen Hill.

The broken ground of the fault, which consists of decomposed sandstone, shale, feldspar, calcite, etc., interspersed with masses of harder sandstone and baked shale, gradually merges into a compact granular sandstone, which, at a distance of 460 ft. from the shaft, was self-supporting, and did not require timbering, which, of course, had been necessary up to this point.

A full face of sandstone continued to Station 274 + 60, 940 ft. from the shaft, where the main overlying body of trap appeared in the heading. The full face of the tunnel was wholly in trap at about Station 275 + 30, and continued in this through to the Western Portal, where the top of the trap was slightly below the roof of the tunnel, with hardpan above. The contact between the sandstone and the overlying trap was very clearly defined, the angle of dip being approximately 17° 40′ toward the northwest.

The sandstone and trap are of the Triassic Period, and the trap of this vicinity is more particularly classified as diabase.

The character of the trap rock varied considerably. At the contact, at Station 275, and for a distance of approximately 200 ft. west, corresponding to a thickness of about 60 ft. measured at right angles to the line of the contact, a very hard, fine-grained trap, almost black in color, was found, having a specific gravity of 2.98, and weighing 186 lb. per cu. ft. The hardness of this rock is attested by the fact that the average time required to drill a 10-ft. hole in the heading, with

a No. 34 slugger drill, with air at 90 lb. pressure, was almost 10 hours. The specific gravity of this rock is not as high as that of some other specimens of trap tested, which were much more easily drilled. This rock was very blocky, causing the drills to bind and stick badly, and, when being shoveled back from the heading, as it fell it sounded very much as though it were broken glass.

The remainder of the trap varied from this, through several changes of texture and color, due to different amounts of quartz and feldspar, to a very coarse-grained rock, closely resembling granite of a light color, though quite hard. The speed of drilling the normal trap in the heading was approximately 20 to 25 min. per ft., as compared with the 60 min. per ft. noted above, the larger amounts of quartz and feldspar accounting for the greater brittleness and consequently the easier drilling qualities of the rock. The normal trap in these tunnels has a specific gravity varying from 2.85 to 3.04, and weighs from 179 to 190 lb. per cu. ft.

The temperature of the tunnels, at points 1 000 ft. from the portals at both ends, remained nearly stationary, and approximately between 50° in winter and 60° in summer, up to the time the headings were holed through, being practically unaffected by daily changes in the temperature outside. At the western end, after the connection with the Central Shaft headings was made, there was almost always a current of air from the portal to the shaft, and ascending through the latter. This tended to make the temperature in this part of the tunnel correspond more nearly with the outside temperature; in fact, the variation was seldom more than 5° Fahr.

Timbering.—These tunnels have been excavated entirely by the center top heading method, almost invariably used in the United States. Timbering, where required, was of the usual segmental form with outside lagging, as shown in several of the photographs. In a few places it was necessary to hold the ground as the work progressed, and, in such cases, crown bars were used in the headings.

There was some little trouble at the Western Portal, where the top of the rock was very near the roof of the tunnel, as shown by Fig. 1, Plate XLII. A side heading was driven at the level of the springing line until a point was reached where the roof was self-supporting, and the timbering was brought out to the face of the portal from that point.

FIG. 1.

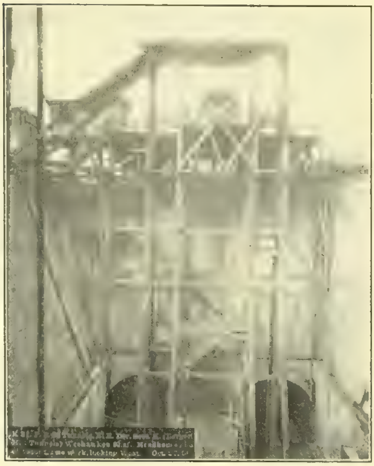


FIG. 2.

FIG. 3.—ROUND HOLES IN CONCRETE FORMS.

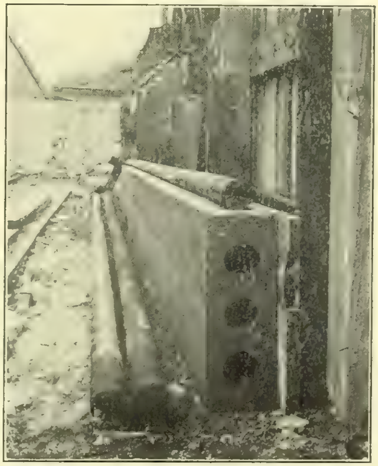


FIG. 4.—ROUND HOLES IN CONCRETE FORMS COMPLETED.

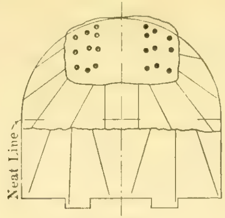
Drilling.—Where no timbering was required, several different methods were used in drilling and excavating the solid rock, though in all cases a center top heading was driven. The four diagrams, Figs. 1, 2, 3, and 4, give typical examples of these methods and show, in the order of their numbers, the general tendency of the development from a small heading kept some distance ahead of the bench, to a large heading with the bench kept close to it. The notes on each diagram give the general details of the quantity of drilling and powder used, methods of blasting, etc., and on the progress profile, Fig. 6, is indicated those portions of the tunnels in which each method was used.

All the drills used throughout the work by Mr. Bradley were Rand No. 34 sluggers, with $3\frac{5}{8}$-in. cylinders, and the steel was that known as the "Black Diamond Brand," $1\frac{3}{8}$-in., octagon. It was used in 2, 4, 6, 8, 10, and 12-ft. lengths; toward the end of the work it was proposed to use 14-ft. lengths, but owing to some delay in delivery this length was never obtained. The starters, 18 to 24 in. long, were sharpened to $2\frac{3}{4}$ to 3-in. gauge, which was generally held up to depths of 6 ft.; then the gauge gradually decreased until it was $1\frac{3}{4}$ to $2\frac{1}{4}$ in. at the bottom of a 12-ft. hole. Frequently, as many as three or four starters were used in starting a hole, and generally two sharpenings were required for each 2 ft. drilled, after the first 6 ft. It is estimated that about $\frac{1}{4}$ in. of steel was used for each sharpening, and that there was an average of one sharpening for every foot drilled.

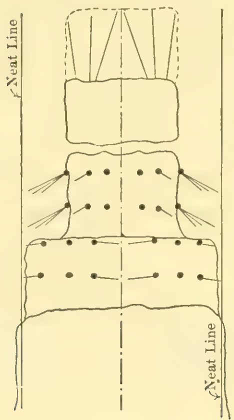
The total quantity of steel used up, lost, or scrapped on the whole work was almost exactly 1 ft. for each 10 cu. yd. excavated, equal to $1\frac{1}{4}$ in. of steel per yard, distributed approximately as follows:

Sharpening	$\frac{3}{4}$ to $\frac{7}{8}$ in.
Other losses	$\frac{1}{2}$ to $\frac{3}{8}$ "
Total..............................	$1\frac{1}{4}$ in. per cu. yd.

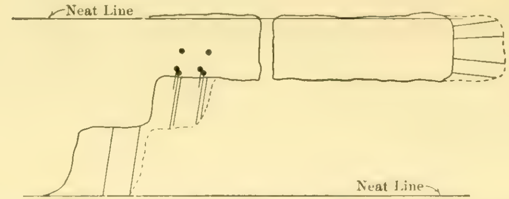
An "Ajax" drill sharpener was used, and proved very satisfactory. Rubber and cotton hose, covered with woven marlin, was used for the bench (3 in. inside diameter, in 50-ft. lengths), for drills (1 in. in diameter, in 25-ft. lengths), and for steam shovels ($2\frac{1}{2}$ in. in diameter, in 50-ft. lengths). Hose coverings of wound marlin, and of woven marlin with spiral steel wire covering were tried, but were not satisfactory, owing to the unwinding of the marlin and the bending of the steel covering.



CROSS-SECTION



PLAN



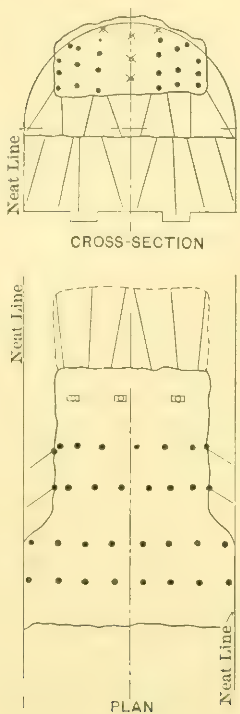
LONGITUDINAL SECTION

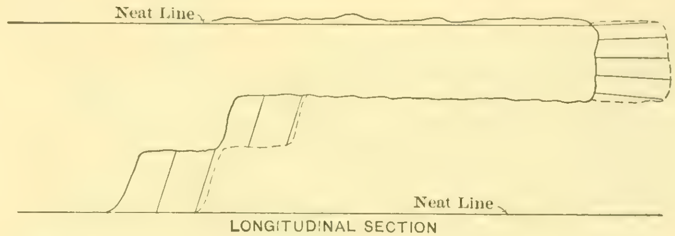
Drilling Method No.1: Small heading, 60 to 80 ft. long. Two columns used in heading, with two drills on each. Drills on sub-bench and main bench mounted on tripods.

	Per Round				Per Cubic Yard		Per Linear Foot of Tunnel		
	Total Depth Drilled	No. of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dy-namite	Cubic Yards	No. of Feet Drilled	Pounds of Dynamite
Heading	140-155	18-21.6	93-131	5-6	8-9	5-6	3.6	29.-32	18-22
Bench	110-120	53-60	76-97	3½-4	2	1.4-1.6	15.4	30.-31	21.5-24.6
						Total	19	59.-63	39.5-46.6
					Per cubic yard, whole tunnel section			3 to 33	2.1-2.5

Blasting Notes:	Number of Sticks
Heading: First Round: 6 sticks, 60%, in each cut hole, cut generally blasted twice	36 to 72
Second Round: 3 side holes each side, 5 sticks, 40% each	30
Third Round: Rest of side holes and dry holes, 5 sticks, 40% each	40
Stub holes, say	5 to 15
Total Sticks	111 to 157
Total Pounds	93 to 131
Sub-bench: 4 widening holes; 2 to 3 sticks each, 40%	10 to 12
6 down holes: 5 to 7 sticks, each, 40%	30 to 42
Bench: 6 holes; 6 to 8 sticks each, 40%	36 to 48
Taking up bottom, average, say	15
Total Sticks	91 to 117
Total Pound	76 to 97

FIG. 1.



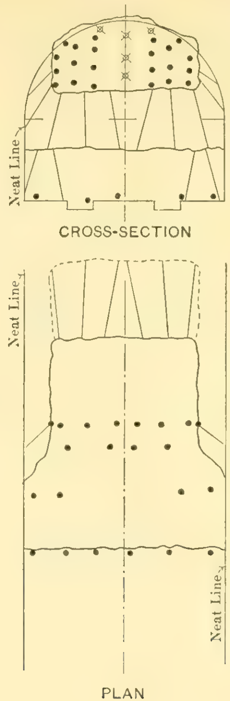


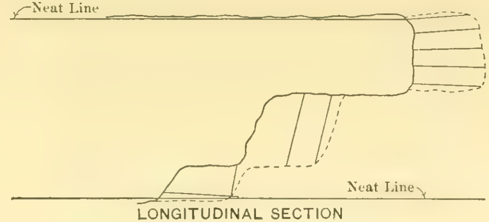
Drilling Method, No.2: Five drills in heading, mounted on three columns; the holes marked with a cross (X) were drilled with the drills on the center column

	Per Round				Per Cubic Yard		Per Linear Foot of Tunnel		
	Total Depth Drilled	No.of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No.of Feet Drilled	Pounds of Dynamite
Heading	190-220	35-42	134-196	6½-8	5.4-6.0	3.9-5.0	5.3	28 to 32.	20.7-26.5
Bench	110-130	55	79-106	4	2.-2.4	1.4-2.0	13.7	27. - 33.	19.2-27.4
						Total	19	55. - 65.	39.9-53.9
						Per cubic yard, whole tunnel section		2.9 - 3.4.	2.1-2.8

Blasting Notes:	Number of Sticks
Heading: First Round; 2 to 3 relieving holes sprung with 4 to 5 sticks each	8 to 15
8 cut holes, 7 sticks each (sometimes shot twice)	56 to 112
First side round, 6 holes, 6 sticks each	36
Widening and dry holes, 10 to 12 holes, 6 sticks each	60 to 72
Total Sticks	160 to 235
Total Pounds	134 to 196
Sub-bench: 8 holes, 4 to 6 sticks each	32 to 48
Bench: 8 holes, 6 to 8 sticks each	48 to 64
Taking up bottom, average	15
Total Sticks	95 to 127
Total Pounds	79 to 109

FIG. 2.



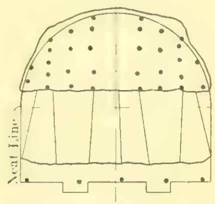


Drilling Method No.3: Heading same as second method, but larger lift taken off bench, and lift holes drilled in bottom bench in order to get down to grade in floor. Bench kept closer to heading.

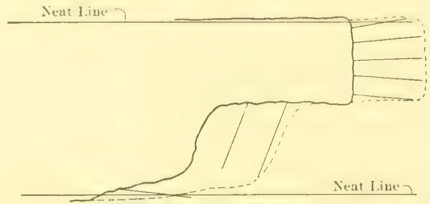
	Per Round				Per Cubic Yard		Per Linear Foot of Tunnel		
	Total Depth Drilled	No. of Cubic Yards	Pounds of Dynamite	Advance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No. of Feet Drilled	Pounds of Dynamite
Heading	190 to 220	35 to 42	134 to 196	6½ to 8	5.4 to 6.0	3.9 to 5.0	5.3	28 to 32	20.7 to 26.5
Bench	145 " 190	90 to 110	118 " 167	6½ " 8	1.6 " 1.9	1.3 " 1.8	13.7	22 " 36	17.8 " 24.7
						Total	19	50 " 58	38.5 " 51.2
						Per cubic yard, whole tunnel section		2.6 " 3.1	2.0 " 2.6

Blasting Notes:	Number of Sticks
Heading: First Round: 2 to 3 relieving holes sprung, with 4 to 5 sticks each	8 to 15
8 cut holes, 7 sticks each (sometimes shot twice)	56 to 112
First side round, 6 holes, 6 sticks each	36
Widening and dry holes, 10 to 12 holes, 6 sticks each	60 to 72
Total Sticks	160 to 235
Total Pounds	134 to 196
Sub-bench: 4 widening holes, 4 to 5 sticks each, 2 rounds	32 to 40
6 down holes, 5 to 7 sticks each, 2 rounds	60 to 84
Bench: 4 down holes, 5 to 7 sticks each,	20 to 28
6 to 8 lift holes, 5 to 6 sticks each	30 to 48
Total Sticks	142 to 200
Total Pounds	118 to 167

FIG. 3.



CROSS-SECTION



LONGITUDINAL SECTION

PLAN

Drilling Method No.4: 8 drills on 4 columns used in heading. Bench taken off in one lift. Bottom taken up with lift holes

	Per Round				Per Cubic Yd.			Per Lineal Foot of Tunnel	
	Total Depth Drilled	No.of Cubic Yards	Pounds of Dynamite	Ad-vance	Linear Feet Drilled	Pounds of Dynamite	Cubic Yards	No.of Feet Drilled	Pounds of Dynamite
Heading	310-320	63-71	215-357	8-9	4.5-5.1	3.4-5.7	7.9	35.6-45.	26.9-45.0
Bench	190-210	89-100	107-155	8-9	1.9-2.2	1.2-1.7	11.1	21.1-24.	13.3-18.9
						Total	19	56.7 69.	40.2-63.9
Per cubic yard, whole tunnel section								3.-3.6	2.1-3.4

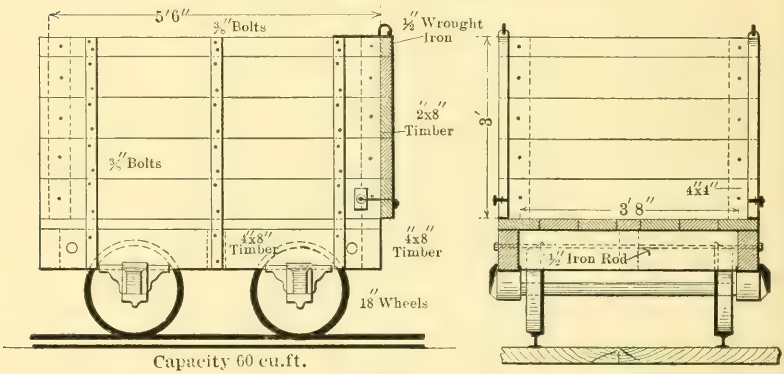
Blasting Notes:	Number of Sticks
All holes of whole round are cleaned and loaded before blasting is started	
First Round:5-6 lift holes,7 to 9 sticks each	35 to 54
First row,sub-bench,6 holes,6 to 8 sticks each	36 to 48
Second Round:Second row,sub-bench and widening holes,8 to 10 holes,	
6 to 8 sticks each	48 to 64
Stub holes	10 to 20
Bench Total Sticks	129 to 186
Total Pounds	107 to 155
Third Round 8 cut holes,7 sticks each,often requires 3 to 4 charges	112 to 224
Fourth Round 8 holes,First side round,5 to 7 sticks each	40 to 56
Fifth Round 8 holes,Second side round,5 to 7 sticks each	40 to 56
2 dry holes 5 to 7 sticks each	10 to 14
Sixth Round 4 to 6 widening holes and dry holes,6 sticks each	36 to 48
Stub holes	20 to 30
Heading Total Sticks	258 to 428
Total Pounds	215 to 357

FIG. 4.

The average quantity of powder used on the whole work was about 2.9 lb. per cu. yd. The tables on the diagrams, Figs. 1, 2, 3, and 4, show that the quantity actually used in making the advance at the main working faces was about 2.5 lb. The difference is accounted for by the larger percentage of powder used for trimming the sides, breaking out the cross-passages between the tunnels, and the excavation of the ditches, the latter operation not being done until the concrete lining was about to be put in.

There was some time, too, during the earlier stages of the work, when it is believed that an excessive quantity of powder was used; for one or two months it ran up to 4 lb. per cu. yd.

MUCK CAR USED AT WEEHAWKEN SHAFT



Capacity 60 cu.ft.

FIG. 5.

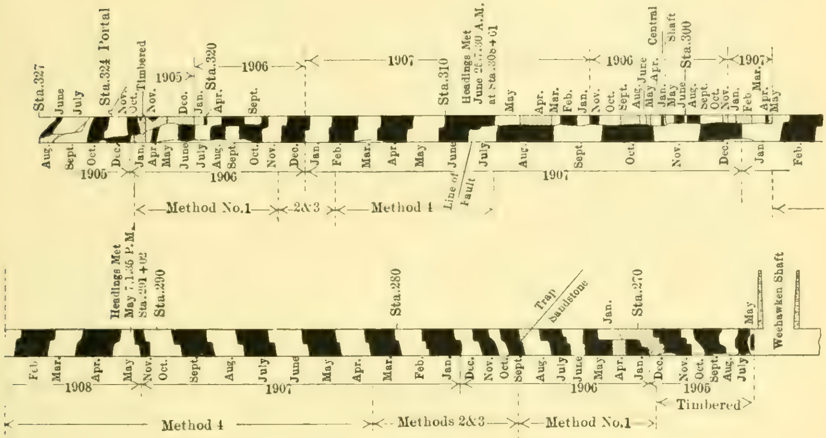
The dynamite used was "Forcite." At first, both 40% and 60% were used, the 60% generally only for blasting the cut in the headings; during the latter part of the work, however, the 60% was used exclusively.

The rock as a rule broke very well, and only a comparatively small quantity could not be handled by the shovels without being broken up further by block-holing. In the sandstone the quantity of powder per cubic yard was much more than for any of the trap.

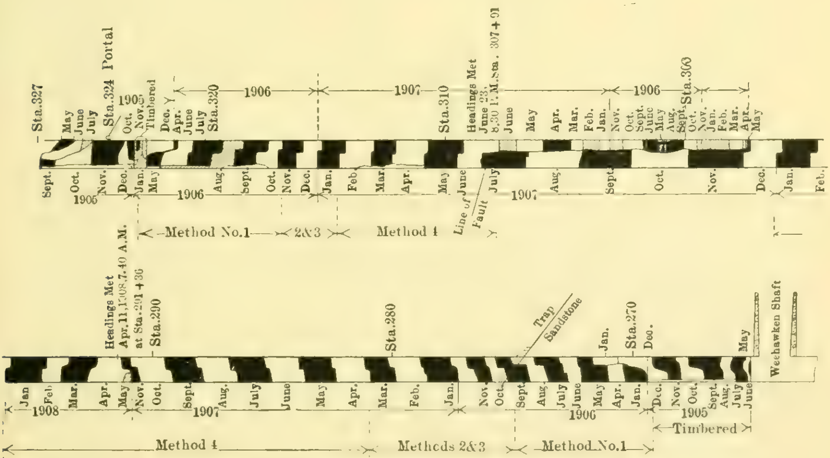
In drilling the Central Shaft, a 6-hole cut was made approximately on the center line, east and west, the enlargement requiring about 18 more holes, which were generally about 6 ft. deep, the average advance being about 4 ft. per day of 24 hours.

The drills were run by steam until a depth of about 150 ft. had been reached, air from the plant at Hackensack being available after

PROGRESS PROFILES OF NORTH AND SOUTH TUNNELS SHOWING MONTHLY EXCAVATION



NORTH TUNNEL



SOUTH TUNNEL

FIG. 6.

that time. Four drills were used most of the time, and six later when air was available. This work was done entirely by the John Shields Construction Company, and a depth of 205 ft. was sunk in 6 months (from July 15th, 1905, to January 15th, 1906). A derrick was used for hoisting and lowering men and tools during the sinking, elevators being put in later.

Drilling Data.—During the progress of the work, both general and detailed observations were made of the drilling, the results of which are shown in the tables. Table 1 has been compiled from the records as platted daily on the chart from the inspectors' reports, as shown by Plate XLIV, and described on page 291. Table 2 contains some data relating to the drilling in the headings.

The general results of these observations show that the average time the drills were "actually working" was 5.2 hours per shift, and that they were actually "hitting the rock" about half of this time, or about 2.5 hours per shift. The average depth drilled per hour, during the time the drills were "actually working," was 2.66 ft.

The "actual working time," as noted above, covers the period from the time the drills were first set up in the heading after blasting until they were taken down for the next blast; it does not include the time occupied in setting up or taking down, which would probably average 30 min. more per shift. It is believed that this figure will also apply very closely to drills working on the bench, though no actual observations were taken to determine this, on account of the irregularity with which they were worked.

The actual working time of the drills in the 736 shifts (7 360 hours) covered by Table 1, was 3 826 hours, or 5.2 hours per shift. The average depth drilled per yard, as shown in the last column of Table 1, agrees fairly well with the figures on the diagrams, Figs. 1, 2, 3, and 4.

Table 2 has been compiled from detailed timed observations of individual drilling of down holes in the bench, for periods of 7 or 8 hours each, in January, 1907. The work at that time was in fairly normal condition at all points.

The figures in the third column of Table 2 include the time required for moving from one hole to another, when this occurred during the observation, the time required for changing bits, oiling drills, etc., and all delays of all kinds. A close record of the delays was

May		19 Sunday	20 Monday		21 Tuesday		22 Wednesday		23 Thursday		24 Friday		25 Saturday	
		6 A.M.	6 P.M.	6 A.M.	6 P.M.	6 A.M.	6 P.M.	6 A.M.	6 P.M.	6 A.M.	6 P.M.	6 A.M.	6 P.M.	6 A.M.
WEEHAWKEN North 1	HEADING				28 Holes, Av. 7'							27 Holes Av. 9'		
	BENCH						20 Holes Av. 7'							
	NO. OF DRILLERS		12	10	12	8	13	11	13	12	13	12	13	11
	" " MUCKERS		12	11	33	12	17	10	17	11	17	12	17	12
	CUBIC YARDS		49	97	7	43	54	48	15	102	33	21	39	98
	SHOVEL													
	Air													
WEEHAWKEN South 2	HEADING													
	BENCH													
	NO. OF DRILLERS		11	9	13	11	14	10	14	12	14	11	14	12
	" " MUCKERS		20	14	15	11	13	14	15	12	15	13	15	8
	CUBIC YARDS		63	0	48	86	12	0	119	56	53	46	84	27
	SHOVEL													
CENTRAL SHAFT North 3	HEADING													
	BENCH													
	NO. OF DRILLERS													
	" " MUCKERS													
	CUBIC YARDS													
	SHOVEL													
CENTRAL SHAFT South 4	HEADING													
	BENCH													
	NO. OF DRILLERS													
	" " MUCKERS													
	CUBIC YARDS													
	SHOVEL													
	Air													
CENTRAL SHAFT North 5	HEADING		24 Holes Av. 7.5'		24 Holes Av. 7.5'		24 Holes Av. 7.5'		24 Holes Av. 7'		24 Holes Av. 7'		27 Holes Av. 7'	
	BENCH													
	NO. OF DRILLERS		2	6	2	6	2	6	2	6	2	6	2	6
	" " MUCKERS		8	11	3	9	6	9	6	9	6	7	6	7
	CUBIC YARDS		11	13	5	11	7	12	9	12	6	13	9	8
	SHOVEL													
CENTRAL SHAFT South 6	HEADING		24 Holes Av. 7.5'		24 Holes Av. 7.5'		24 Holes Av. 7.5'		24 Holes Av. 7'		22 Holes, Av. 7.5		24 Holes Av. 7'	
	BENCH													
	NO. OF DRILLERS		2	6	4	6	2	6	2	6	2	5	2	5
	" " MUCKERS		4	7	3	8	5	7	5	8	5	8	5	6
	CUBIC YARDS		13	24	7	15	9	10	8	13	6	10	10	10
	SHOVEL													
HACKENSACK North 7	HEADING				31 Holes, Av. 9.5'			31 Holes, Av. 9.5			32 Holes, Av. 9.5			
	BENCH													
	NO. OF DRILLERS		11	13	12	12	13	12	13	13	14	12	13	12
	" " MUCKERS	17	10	17	11	15	11	14	11	17	12	16	13	16
	CUBIC YARDS		25	74	19	19	12	63	4	48	96	8	4	67
	SHOVEL													
	Air													
HACKENSACK South 8	HEADING		32 Holes Av. 11'		32 Holes, Av. 9.5						33 Holes Av. 9.5'			
	BENCH													
	NO. OF DRILLERS		8	10	12	13	12	13	12	13	14	12	14	12
	" " MUCKERS		14	14	16	13	15	12	12	17	10	16	10	17
	CUBIC YARDS		48	90	19	6	27	141	2	63	63	8	19	145
	SHOVEL													

RECORD OF DRILLING, AIR PRESSURE, MUCKING, ETC.

kept, and it was considered that, of the 93 hours, 48 min., in Table 2, the unnecessary delays amounted to 5 hours, 7 min., or about 5½ per cent.

TABLE 1.

Method.	Date.	Number of shifts covered by observations.	Place.		Average number of hours worked per shift.	Average depth drilled per hour per drill.	Average depth drilled per yard.
No. 1—4-drill......	Aug. '06	44	Hackensack,	N.	5.69	2.78	10.1
	Sept. '06	33	"	N.	5.80	3.77	11.1
	Aug. '06	43	"	S.	5.60	2.89	9.1
	Sept. '06	36	"	S.	6.18	2.65	8.7
	Jan. '07	16	Central Shaft E.	N.	5.99	2.99	8.2
	Jan. '07	20	"	S.	6.05	2.9	7.1
	Apr. '07	48	Central Shaft W.	N.	4.92	3.3	6.7
	Apr. '07	48	"	S.	5.00	3.2	7.7
Nos. 2 and 3—5 drill......	Dec. '06	54	Weehawken,	N.	4.95	2.16	4.52
	Dec. '06	54	"	S.	5.23	2.14	4.54
	Dec. '06	52	Hackensack,	N.	5.63	2.2	5.77
	Dec. '06	54	"	S.	5.90	1.82	5.67
No. 4—7-drill......	June '07	56	Weehawken,	N.	4.77	2.55	4.23
	June '07	58	"	S.	4.82	2.26	3.88
8-drill......	May '07	60	Hackensack,	N.	4.67	2.44	5.00
	May '07	60	"	S.	4.54	2.57	4.80

TABLE 2.

Date.	Place.		Total working time. Hours.	Minutes.	Number of feet drilled.
Jan. 14th, 1907...........	Weehawken	N..........	8	0	15
" 15th, 1907...........	"	N..........	7	32	12
	"	N..........	7	22	14
" 12th, 1907...........	"	S..........	8	0	20
	"	S..........	8	0	11
	"	S..........	8	0	10
" 11th, 1907...........	Hackensack	N........	8	0	13
" 17th, 1907	"	N..........	7	10	10
	"	N..........	7	5	11
	"	N..........	7	10	10
" 16th, 1907...........	"	S..........	4	20	10
	"	S..........	6	9	10
	"	S..........	7	..	8
Totals.............	....		93	48	154

Average: 36.6 min. per ft. drilled, or 1.64 ft. drilled per hour.

As a check on the average figures obtained from various sources, the following estimate of the cost of drilling per cubic yard was made up from these average figures, for comparison with the actual average cost on the whole work. The cost records show this to be about $2.25 per yd., exclusive of power for running the drills, almost exactly what

the following estimates give for theoretical average conditions, although no effort was made to have this latter compare so closely.

Estimated Cost per Drill per Day.

Drill Runner	1	at $3.50	per day,	$3.50
Helper	1	" 2.00	" "	2.00
Nipper	$\frac{1}{5}$	" 1.75	" "	0.35
Heading foreman	$\frac{1}{12}$	" 5.00	" "	0.42
Walking boss	$\frac{1}{50}$	" 7.50	" "	0.15
Blacksmith	$\frac{1}{12}$	" 4.00	" "	0.34
Blacksmith helper	$\frac{1}{12}$	" 2.00	" "	0.16
Machinist	$\frac{1}{12}$	" 3.00	" "	0.25
Machinist helper	$\frac{1}{24}$	" 1.75	" "	0.07
Pipe fitter and helper	$\frac{1}{50}$	" 5.00	" "	0.10
Oil, waste, blacksmith coal, etc.				0.24
Drill steel, 6 in. per shift				0.20
				$7.78

Average number of feet drilled per cubic yard .... 3 to 3.5

Number of feet drilled per drill, per shift .... 10 5 to 12

Number of yards per drill, per shift .... 3.5±

Cost of drilling, per yard, $\frac{\$7.78}{3.5}$ .... $2.22±

In all the foregoing tables and computations, the quantities used have been those paid for. The quantity taken out, however, has been 10% more than that paid for, and 28% more than the contractor was actually required to take out.

The specifications required that the excavation should be taken entirely outside of the neat line, as shown on Plate XXXII of the paper by Mr. Jacobs, but not necessarily beyond this line, but that the contractor would be paid for rock out to the standard section line, which is 1 ft. larger on the sides and top and 6 in. deeper in the bottom than the neat line.

A great deal of the extra quantity was due to rock falling from the core-wall side whenever one working face was behind the other. Blasting at the face behind generally loosened more or less rock on the core-wall side of the tunnel which was ahead, in one or two instances breaking entirely through, as shown in Fig. 2, Plate XLVII, the hole in the core-wall in this case being utilized by building a storage chamber in it.

Table 3 gives some of the statistics of drilling in the Simplon Tunnel, as compared with the drilling on this work, the figures for the Simplon being taken from papers read before the Institution of Civil Engineers of Great Britain.

TABLE 3.

	Bergen Hill.	Simplon.
Drills set up in heading, percentage of total elapsed time	50%	60%
Actually drilling the rock, percentage of total elapsed time	25%	50%
Average advance per round (attack)	8.5 ft.	3.8 ft
Average time for each attack	36 hours.	5 hours.
Average advance per day of 24 hours	5 ft.	18 ft.†
Depth of holes	10 ft.	4.6 ft.
Diameter of holes	$2\frac{3}{4}$ in.	$2\frac{3}{4}$ in.
Linear feet drilled per hour, per drill	2.7	7.0
Linear feet drilled per cubic yard	5.0	6.0
Pounds of dynamite per cubic yard	3.4 to 5.7	$8\frac{1}{2}$
Average depth drilled with one sharpening	12 in.	$6\frac{1}{2}$ in.
Total number of men per day of 24 hours*	450	3 300

*On Bergen Hill Tunnels, for two full working faces at the Hackensack end, about 3 000 ft. in from portal (March, 1908). At Simplon, two full faces and two headings, at a distance of about 5 000 ft. in from the portal (January, 1900). These both include lining as well as excavation. The lining of the Bergen Hill Tunnels progressed about twice as fast as the excavation; it is inferred that on the Simplon it progressed at about the same rate as the excavation.

†At the Italian end, in Antigoric gneiss, which is stated to be very hard rock.

The figures in Table 3 are for "heading only" in both cases, except for the last item (number of men), the heading in the Simplon Tunnels being about 60 sq. ft., as compared with the heading of Method No 4 (which has been used for comparison), of 210 sq. ft.

Mucking and Disposal.—The conditions affecting the disposal of the muck, after blasting, were quite different at the two ends, the grade descending in the direction of the loads at Weehawken and ascending at the Hackensack end. At the Weehawken end the mouth of the tunnels was at the bottom of a shaft some 80 ft. deep, Fig. 2, Plate XLIII, the muck in the tunnel cars being hoisted by elevators to a platform at the top from which it was dumped into standard-gauge cars supplied by the Erie Railroad, as shown by Fig. 7; or later hauled to the crusher or storage pile, some 500 ft. distant, on the north side of Baldwin Avenue. At the western end, the cars were hauled directly to the surface through the approach cut, and the material, except that required for concrete and rock packing, was deposited in the embankment across the Hackensack Meadows, a haul of from 1 000 to 3 000 ft. beyond the portal.

All disposal tracks were of 3-ft. gauge, the main running tracks being generally laid with 60-lb. second-hand rails, although some of lighter weight were used.

Except for about 1 000 ft. in each tunnel at the Weehawken end, where the muck was loaded by hand, four steam shovels, operated by compressed air, were used, one at each working face. One of these was a "Marion, Model No. 20," weighing 38 tons, the others were "Vulcan Little Giant," of about 30 tons each. All these shovels were on standard-gauge track, and were moved back from 300 to 500 ft. from the working face during blasting.

At Weehawken, previous to the time the shovels were installed, the muck was shoveled by hand into the cars from the bottom of the bench, and the heading muck was dumped into them from the movable platform (Jumbo) shown by Fig. 1, Plate XLIII. There were three loading tracks at the face. The cars used at that time were

METHOD OF EMPTYING DUMP CARS AT WEEHAWKEN SHAFT

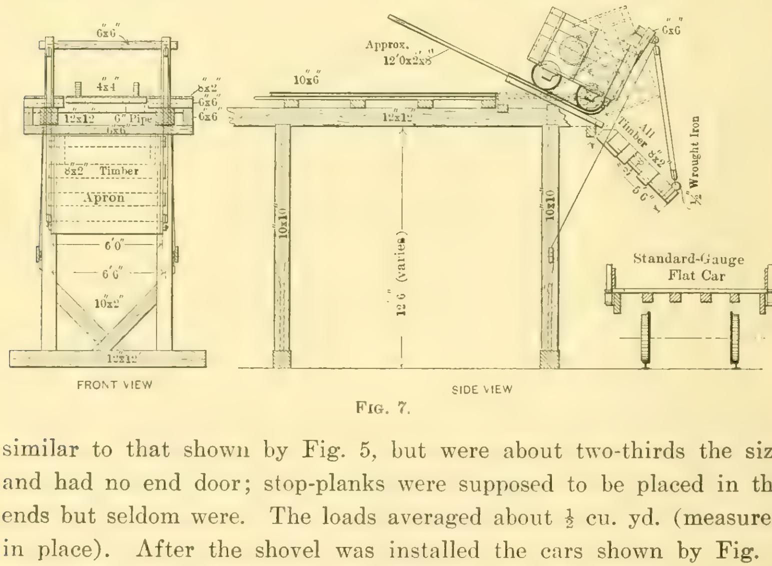


Fig. 7.

similar to that shown by Fig. 5, but were about two-thirds the size and had no end door; stop-planks were supposed to be placed in the ends but seldom were. The loads averaged about ½ cu. yd. (measured in place). After the shovel was installed the cars shown by Fig. 5 were used, and the loads averaged nearly 1 cu. yd.

The empty cars were pushed up to the shovel by hand from the storage track. When loaded, they were given a start with the bucket of the shovel, and were then allowed to coast by gravity out to the storage track near the shaft, where they were stopped by placing rolls of cement bags or burlap on the rails. After the lining was started, the loaded cars were stopped on the inside of the lining and only sent out over the single track through this latter at stated intervals,

when several cars followed in close succession, with a long interval which permitted the concrete to be brought in. The empty cars were hauled back to the storage track near the working face by mules, one mule usually hauling two cars at a time.

Up to the time the trap rock was reached, about 1 100 ft. from the shaft, the excavated material was disposed of by loading it on flat cars. All the trap, however, was stored to be used later for concrete and ballast.

When the tunnels were in full working order, sixty muck cars of the type shown by Fig. 5, were in use, about evenly divided between the two tunnels. For some time the work was greatly hampered by lack of cars, and even with the sixty finally obtained, there were many times when extra cars could have been used to advantage to keep the shovel working.

When mucking by hand, the mucking gangs consisted of from 15 to 20 men. The maximum output was 50 cu. yd., and averaged about 35 cu. yd. per shift; there was a great deal of trouble in keeping the gangs full, as labor at that time was very scarce, and the tunnels were quite wet. The maximum output of either of the shovels was 159 cu. yd. in one shift, and the best average in any month—which was between July and December, 1907, during which time only the enlargement and bench of the Central Shaft headings was being taken out from the western end—was 60 cu. yd. per shift. As the shovels were generally idle for one shift out of three, the quantity actually handled averaged 90 cu. yd. per shift during the shifts the shovel worked. All these quantities were "measured in place," and, as previously noted, would be about equal to twice as much measured loose in the cars.

The shovels at both ends were usually worked with three crews for the two tunnels; two day crews, one at each shovel, and a night crew which was used in either tunnel as occasion required. The day crews generally averaged from 45 to 60 hours overtime during the month, one of them working during the early part of the evenings in the opposite tunnel to the night crew. For a short time, when the ventilation at the western end was very bad, four crews were worked, day and night crews in each tunnel; but, as a general rule, the method of working three crews was preferred by the men, and was less expensive for the contractor.

At the Hackensack end, 4-yd., Allison, one-way, dump cars were used, being handled by dinky locomotives, of which there were three in use up to October, 1907, and four after that. One 15-ton Porter engine, with 10 by 16-in. cylinders, was used outside the tunnels for handling the trains (from 6 to 8 cars) on the dumps and to the crusher; the other three, 12-ton Vulcans, 9 by 14-in., were used in the tunnels. About 30 dump cars were in use, and of these there were generally from 3 to 6 under repair.

Generally, 4 cars were hauled out together, although 5 and occasionally 6 were handled. The work was generally arranged so that the heavy mucking shift alternated in the two tunnels, the two engines being worked there and a single engine in the other tunnel.

The tunnel engines left the cars on a track just outside the portal, from which they were made up into trains of from 6 to 8 cars and taken to the dump or crusher by the large dinky.

The muck from the Central Shaft headings was loaded by hand into cars similar to that shown by Fig. 5, but smaller and having no door at the forward end. A double elevator took the cars to a platform about 20 ft. above the surface, where they were dumped by revolving platforms, similar to those at Weehawken, into storage bins or directly into wagons. The muck was all hauled away in wagons; part of it was used to fill some vacant lots, and part was hauled to the crusher at the Western Portal.

The method under which the best results were obtained was that in which a full round was blasted every 36 hours, securing an advance of practically 9 ft. of full section. During the first shift of the three, as soon as the blasting had been completed and lights strung, the shovel was moved forward, and cleaned up the floor to the main pile of muck, the material from the blast being scattered from 150 to 300 ft. back from the face; during this shift, also, the drillers mucked the heading and set up their drills, the muckers helping to carry in the columns and drills. During the second shift the main pile of muck was disposed of, leaving not more than 2 or 3 hours' work for the shovel on the third shift. This left nearly the whole of the third shift for drilling the lift holes.

Ventilation.—At Weehawken considerable difficulty was caused by fog and smoke accumulating in the tunnels after blasting. This was generally worse on days when the barometric pressure was low out-

side, and worse in the North than in the South Tunnel. A 6-ft. fan, driven by an electric motor, was installed in the cross-passage at Station 274, 900 ft. from the shaft, the headings at that time being about 300 ft. in advance of this point, to force the air from the South into the North Tunnel, drawing it in at the mouth of the South Tunnel and discharging it at the mouth of the North Tunnel, thus insuring a circulation in both tunnels, as shown in plan by Fig. 8.

This necessitated, of course, that the cross-passages between that in which the fan was placed and the mouths of the tunnels should be blocked tight. There was some difficulty in keeping this blocking tight, owing to the force of the blasting blowing out the bulkheads. The fan, however, did good service when it and the bulkheads were in good order. The compressed air discharged from the drills kept the headings fairly clear, as well as that part of the tunnel between the headings and the fan. The fan was moved ahead to the next cross-

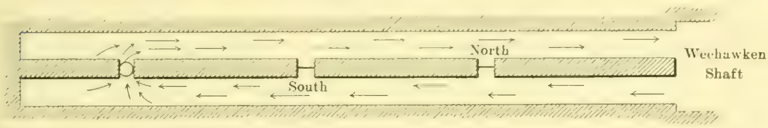


FIG. 8.

passage at Station 277 when the work had progressed far enough, and was used there for some time; it was found, however, that by the time the excavation had reached Station 280, about 1 500 ft. from the shaft, there was practically no further difficulty from fog and smoke. No satisfactory explanation was found for this, as it would rather be expected that the ventilation and trouble with smoke and fumes from blasting would be worse as the distance increased between the mouth of the tunnel and the working face. One explanation was offered: That the blasting of the softer sandstone tended to create more and lighter dust than the heavier trap rock; whether or not this was so, it is a fact that there was far less trouble with fog and smoke after the sandstone was passed.

At Hackensack, the principal cause of trouble was the smoke from the "dinky" locomotives. As the tunnels progressed, this gradually became worse, until a connection was made with the Central Shaft headings. A fan was installed in the cross-passage at Station

316 (700 ft. in from the portal), but was never worked properly. Apparently, the men, at least the walking bosses and foremen, had little faith in the fan as a means of ventilation; no real attempt was made to keep it in order or operate it properly, and a great deal of time and money was lost groping around in the smoke and fog, the density of which increased, not only with the state of the atmosphere, but also with the direction of the wind. On some days the tunnels easily cleared themselves, and on others the smoke was so thick that a candle held at arm's length could not be seen. At this end, the South Tunnel was generally worse than the North. After the headings were holed through between the portal and the Central Shaft there was very little trouble, there being usually a strong up-draft through the shaft. This was so pronounced when the wind was blowing toward the portal, that the moisture-laden air, as it ascended from the mouth of the shaft, presented the appearance of a heavy rainstorm with the rain ascending instead of descending. When the wind was blowing away from the portal, that is, from the southeast, the effect of the shaft as a chimney was neutralized, and, consequently, the smoke accumulated in the tunnels. To overcome this, a large blower, with a fan 9 ft. in diameter, and with blades 4 ft. wide and 2 ft. 3 in. long, operated by a vertical 12-h.p. engine, was installed at the top of the shaft, and this kept the tunnels reasonably clear of smoke at all times. After the bench and enlargement had passed the bottom of the shaft, the use of the fan was abandoned, as it was found that the tunnels cleared themselves fairly well, probably owing to the larger cross-section reaching all the way to the Shaft. What little fog and smoke there might be did not cause enough trouble to warrant the cost of running the fan, which, owing to its location, required the whole time of a mechanic in attendance day and night.

Lighting.—During the earlier stages of the work, gasoline lamps and Kitson lights were used. The former, of the familiar banjo type, and a modification of this, with a section of wrought-iron pipe for the reservoir, were very unsatisfactory, and were out of repair and leaking a large proportion of the time. The Kitson lights were given only a short trial, but were found unsatisfactory, owing to the necessity of moving them frequently and having to set them up in insecure positions. Electric lights were installed by Mr. Bradley, on his assumption of the contract.

The number of lamps maintained in each of the tunnels for the excavation was approximately as follows:

At the main working face................	From	8 to 10
On and around the shovel...............	"	9 to 12
Between the portal and the working face..	"	60 to 80

The cost of lighting for the whole work averaged about 15 cents per cu. yd., which is quite large. This was mainly due to the fact that current was bought from outside sources during a large part of the time (one-third of the yardage). Part of this current cost 5 cents per kw.-hr., and there were fairly heavy charges for connecting the tunnel wiring system with the source of supply. Current bought from the Public Service Corporation cost from 10 to 12 cents per kw.-hr. delivered at the mouth of the tunnel.

Pumping.—The quantity of water encountered during the excavation of the tunnels, measured somewhat roughly, was approximately as follows:

At Weehawken	74 gal. per min.
At Central Shaft	1 " " "
At Hackensack	18 " " "

The water at the Weehawken end had to be pumped from the bottom of the shaft, a lift of about 90 ft., while at the Hackensack end it had to be pumped back from the face up grade to the portal.

The cost of pumping was about \$100 to \$125 per month for labor for the whole work, besides the cost of the plant (about \$1 200) and the power for running it.

Progress.

The total time elapsed from the time of starting work at the Weehawken end, in May, 1905, to the completion of the excavation, in May, 1908, was almost exactly three years. Of this time about 40 days were lost in February and March, 1906, when work was stopped by the Receiver of the Shields Company, the total number of days actually worked being about 940, giving an average progress of 6.26 ft. per working day in each of the two tunnels, which, omitting the Central Shaft headings, gives an average rate of progress for each working face, of 3.13 ft. per day.

These 940 days include practically all the time elapsed, except Sundays and such few holidays as were observed. For some of this time, work was being carried on at only one or two points; the time, therefore, represents practically the total possible working time during the period covered.

Progress at Weehawken.—At Weehawken the total number of days worked was 763, divided as follows:

186 days in timbered section, about 426 ft., an average rate of 2.3 ft. per day in each tunnel;

176 days in hard sandstone, about 563 ft., an average rate of 3.2 ft. per day in each tunnel;

112 days in hard trap, about 267 ft., an average rate of 2.4 ft. per day in each tunnel;

289 days in ordinary trap, about 1 316 ft., an average rate of 4.55 ft. per day in each tunnel.

Progress at Central Shaft.—At Central Shaft the average length driven per day in each of the four headings is shown by Table 4.

TABLE 4.

Location.	Number of days worked.	Total length of heading, in feet.	Average length of heading driven per day worked, in feet.
N. E.	227	446	1.96
S. E.	168	346	2.06
N. W.	272	768	2.82
S. W.	234	698	2.98

Progress at Hackensack.—At Hackensack the total number of days worked on the tunnels proper, all in trap rock (omitting the cut and cover) was about 792, divided as shown in Table 5.

TABLE 5.

Location.	Number of days worked.	Advance.	Average advance per day.
Station 323 to Central Shaft headings...............	492	1 450	4.5
Bench and enlargement of Central Shaft headings	159	1 150* 906†	7.2* 5.7†
Central Shaft headings to Weehawken headings...	141	620	4.4

* Actual advance. † Equivalent linear feet of full section tunnel.

The best month's work in each location was as follows, the actual yardage excavated and paid for being reduced to equivalent linear feet of full section. The tunnels were generally taken out to full section, except for a small amount left in the bottom, which latter reduced the equivalent linear feet of full section to about 95% of the actual advance at the face.

Weehawken.—

			Linear feet.	Feet per day.
Full timbered section,	North Tunnel. .	Nov., 1905,	87 =	3.0
Sandstone	" " . .	May, 1906,	109 =	3.9
Trap (normal)	South " . .	July, 1907,	144 =	5.3

Hackensack (All trap).—

		Linear feet.	Feet per day.
Portal to Central Shaft headings, South Tunnel. .	May, 1907,	139 =	5.0
*Enlargement of headings, " " . .	Nov., 1907,	175 =	6.0
Central Shaft headings to Weehawken headings, North Tunnel	Apr., 1908,	145 =	5.2

Central Shaft Headings.—During April, 1907, 122 lin. ft. of heading, averaging 3.8 cu. yd. per lin. ft., were taken out in the South Tunnel, west of the shaft. This was equal to 5.0 ft. per day for the 24 days worked.

The Best Week's Work.—The best week's work at either of the main working faces, when the full section was being excavated in trap rock, was 803 cu. yd., equal to 41.8 lin. ft. of full-section tunnel, or an average of 6.0 lin. ft. of full section per day; this was from the South Tunnel at Hackensack for the week ending January 11th, 1908.

The Best Yardage.—The largest number of yards taken out in any one week from one working face was 1 087, equivalent to 56.6 lin. ft. of full section, or an average of 8.1 lin. ft. of full section per day. This was bench and enlargement only (Central Shaft headings) in the North Tunnel, Hackensack, for the week ending October 19th, 1907.

The largest yardage for the whole work in any one week was 3 238 cu. yd. from four working faces—two at Weehawken in full section and

* The actual advance of the bench this month was 202 lin. ft.

two at the Hackensack bench and enlargement (Central Shaft headings). This was equivalent to 168.4 lin. ft. of full-section tunnel, or an average of 6 ft. per day from each working face.

The Best Month's Work.—The best month's work with each of the four methods of drilling the headings, as shown in Figs. 1, 2, 3, and 4, where the work was straight forward and the full section was being taken out, was as follows:

Method No. 1................	About 90 ft.	in sandstone.
" No. 2................	" 100 "	in trap.
" No. 3................	" 137 "	in trap.
" No. 4................	" 145 "	in trap.

In regard to these figures it should be noted, as stated previously, that the organization of the men and plant was not properly completed until near the time Method No. 4 was put in operation.

In Fig. 9 is shown graphically the relation of the progress to the time elapsed in the North Tunnel, the diagram for the South Tunnel being almost exactly the same.

Plant.

The plant installed by the John Shields Construction Company, and taken over by Mr. Bradley, was composed very largely of second-hand material, and eventually most of it had to be replaced. Insufficient and inefficient plant and delay in installation were largely responsible for the small progress made by the Shields Company, and Mr. Bradley's endeavor to utilize this plant not only caused much delay during the first 8 or 10 months after he started work, but also involved large expense.

Power Plant.—At Weehawken the plant installed by the Shields Company consisted of three old locomotive boilers, each having a nominal capacity of about 125 h.p., and one Rand and one Ingersoll-Sergeant compressor, each of a rated capacity of about 1 250 cu. ft. of free air per min. compressed to 100 lb.

To this Mr. Bradley added two more second-hand locomotive boilers, and another Rand compressor of the same type and capacity as the first. The theoretical steam capacity of each of the five old locomotive boilers was about 4 250 lb. per hour, or a total capacity of 21 250 lb. per hour.

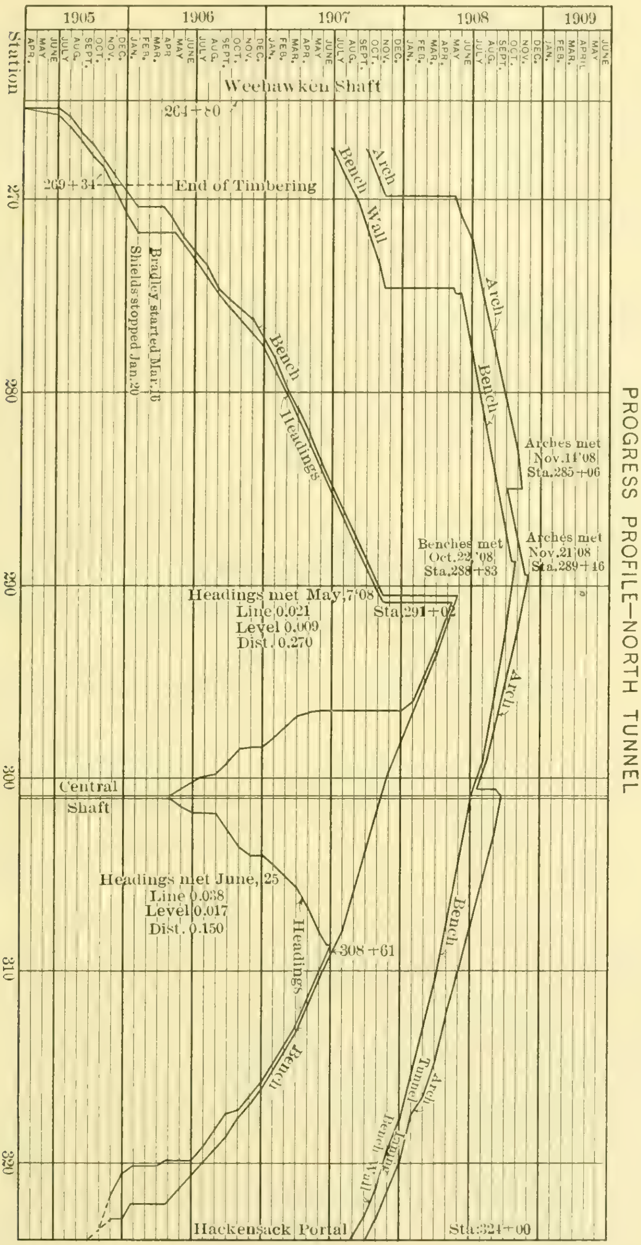

PROGRESS PROFILE—NORTH TUNNEL
1905
1906
1907
1908
1909
Station
Weehawken Shaft
264+80
269+34
End of Timbering
Bradley started Mar.16
Shields stopped Jan.20
Bench
Headings
Bench Wall
Arch
Arches met Nov.14'08 Sta.285+06
Benches met Oct.22'08 Sta.288+83
Arches met Nov.21'08 Sta.289+46
Headings met May,7'08 Line 0.021 Level 0.009 Dist. 0.270
Sta.291+02
Central Shaft
Headings met June,25 Line 0.038 Level 0.017 Dist. 0.150
308+61
Tunnel
Bench Wall
Hackensack Portal
Sta.324+00
270
280
290
300
310
320

Fig. 9.

Theoretically, the demand on this steam was:

		Pounds per hour.
Three compressors, about 5 600 lb. per hour each		16 800
One dynamo	About	1 000
One 500-gal. pump	"	1 000
One hoisting engine for elevators	"	2 000
Total		20 800

Actually, there was considerable deficiency of steam when an endeavor was made to work the three compressors at their full capacity. A separate boiler was afterward installed to run the hoisting engine for the elevators and the pumps, thus leaving a requirement of only approximately 18 000 lb. of steam per hour, but even this was beyond the capacity of the boilers, especially as one was almost always out of commission.

The two Rand compressors were 24 by 24 by 30-in., straight-line, one-stage, steam-driven, with a nominal capacity of 1 250 cu. ft. of free air per min. at 80 rev. per min. The Ingersoll-Sergeant was of similar type and capacity. Therefore, the theoretical quantity available was 3 750 cu. ft. of free air per min.

The theoretical air requirements (as taken from manufacturers' catalogues) were:

	Cubic feet of free air per minute.
20 Rand slugger drills (12 by 174)	2 088
2 Little Giant shovels (taking air two-thirds of the time)	1 100
Total	3 188

This estimate, based on the assumption (given in the catalogues) that the drills would be working about three-fifths of the time, and the shovels about two-thirds of the time, left apparently an ample margin between the full capacity of the compressors and the requirements for the drills; as a matter of fact, however, it was seldom that more than 80 lb. of air was available, and the pressure often dropped to 60 or 50 lb. at the compressors. During the time this plant was in use the greatest distance to the drills was about 1 500 ft.

As this plant proved to be entirely inadequate to the demands, an arrangement was made with the O'Rourke Construction Company on

August 17th, 1906, whereby they agreed to supplement the air supply by 1 000 cu. ft. of free air per min. at 100 lb. pressure. This arrangement was not altogether satisfactory, and finally (on December 5th, 1906) an arrangement was made with the same company to supply air up to 4 000 cu. ft. of free air per min. at 100 lb., and the old plant was shut down.

The new plant had been in use previously in the construction of the River Tunnels. The air from it was compressed to 40 lb. by low-pressure machines, one being used all the time and two when necessary. These machines were built by the Ingersoll-Sergeant Company, the engines being of the Corliss duplex type, cross-compound steam, with simple duplex air cylinders, each compressor having a capacity of nearly 4 000 cu. ft. of free air per min. This air, at 40 lb., was delivered to an Ingersoll-Sergeant high-pressure machine, having Corliss cross-compound engines, 14 by 26 by 36-in., with air cylinders of the piston inlet type, $13\frac{1}{4}$ by 36-in., which compressed it to 100 lb. The capacity of this latter machine, taking air at normal pressure, is 920 cu. ft. of free air per min. working at 85 rev. per min.; by taking the air at 40 lb., and working at a somewhat higher speed, this machine alone supplied all the air used at the Weehawken end (approximately 4 000 ft.) from December, 1906, to November, 1907, and, with very few exceptions, the pressure was steadily maintained at from 90 to 100 lb., there being no break-down of any kind.

At Hackensack the plant taken over by Mr. Bradley consisted of six old locomotive boilers and four Rand compressors, all of the same type as those at Weehawken. To this he added two second-hand marine boilers, each of a stated capacity of about 350 h.p., and two more Rand compressors of the same type and capacity as the others, making the total theoretical steam power available approximately 1 450 h.p., with a compressor capacity of approximately 7 500 cu. ft. of free air per min., equal to about 1 500 h.p., allowing for 15% of loss.

Nowhere near the theoretical steam power was ever developed from the boilers. The tubes of the old locomotive boilers were filled with mud in many cases, and were always leaking. The marine boilers were not properly installed to give the best results, and it was seldom possible to work more than four compressors at once, or to keep the air pressure at the power-house much greater than from 70 to 80 lb. at any time.

This plant had been built by the Shields Company on the meadows alongside the Erie and New York, Susquehanna and Western Railroads, and the foundations were not made sufficiently strong to resist the effect of the vibration caused by the passing trains. It was impossible to keep the steam connections tight, and there was not only the loss of steam due to leaky joints, but positive danger of one of the main steam lines breaking entirely. After attempting to operate this plant for nearly 5 months, Mr. Bradley determined to abandon the site and the boilers, and build a new plant, farther back from the railroad, on solid ground, in such a position that a spur track could be built to a coal trestle in front of the boilers.

Two pairs of Stirling boilers, with a total capacity of 2 000 h.p., were installed. As a rule, at times of maximum demand, three of the boilers were in use; after the Central Shaft was stopped, two were generally sufficient, until, toward the latter part of the excavation, the losses in the transmission of the air made it necessary to keep three going.

Eight compressors (the six old ones with two brought from Weehawken), were installed in the new power-house. All were of the same type, namely, Rand, straight-line, steam-driven, 24 by 24 by 30-in., each with a nominal capacity of 1 250 cu. ft. of free air per min. Seven of these were generally worked to their full capacity in order to keep up the necessary supply of air.

The maximum requirements of air at this end were primarily estimated as follows:

Central Shaft, four headings	24 drills.
Hackensack, two working faces	20 drills.
Total	44 drills.

	Cubic feet of free air per minute.
44 Slugger drills (25 by 174) require	4 350
2 Steam shovels	1 600
Pumps and machine-shop, say	1 000
4 Hoisting engines, placing concrete	2 000
4 Derricks	2 000
Total	10 950

The theoretical capacity of the whole eight compressors was:

$$1\,250 \times 8 = 10\,000 \text{ cu. ft. of free air per min.}$$

It was considered that not more than two-thirds of the above equipment would be working at the same time; the actual requirement, therefore, was taken at about 8 000 cu. ft. of free air per min., thus leaving a margin of one spare compressor.

As actually worked out, there were probably never more than eight drills working at any one time at the Central Shaft, and this work was entirely suspended in June, 1907, before there was any demand for power in connection with the tunnel lining. The heaviest actual requirement, therefore, was approximately as follows:

(A) Previous to June 25th, 1907:

	Cubic feet of free air per minute.
40 Drills (22 by 174)	3 828
2 Shovels	1 600
Pumps and machine-shop, say	1 000
2 Derricks	1 000
Total	7 428

(B) After November, 1907 (after completion of enlargement of Central Shaft headings):

	Cubic feet of free air per minute.
32 Drills (17 by 174)	2 958
2 Shovels	1 600
Pumps, etc.	1 000
3 Hoisting engines on concrete, each working one-third time	500
2 Derricks	1 000
Total	7 058

The average number of drillers per shift was about 25 at the two main working faces. There were also from 5 to 10 drills trimming and cleaning up for concrete, say an average of 7, making 32 in all.

After November 1st, it actually required three boilers under steam all the time, and not less than seven compressors running at full capacity, to keep the air at proper pressure, the theoretical capac-

ity of the compressors being 8 750 cu. ft. of free air per min., as against 7 000 to 7 400 cu. ft., the theoretical maximum requirement.

Some of this deficiency was due to losses in transmission, part also was due to the fact that the actual was probably considerably below the theoretical capacity of the compressors.

Accidents.

Two accidents occurred to the powder magazines, the causes of which were never absolutely determined. The first occurred on January 10th, 1907, when the dynamite burned up without exploding. The second accident was on March 3d, 1907, when an explosion occurred which damaged property over a very large area, but did not involve any serious injury to persons, only one man being slightly hurt.

The only serious blasting accident in the tunnels occurred on January 26th, 1908, and was due to a premature blast, the cause for which could not be ascertained.

Contractor's Organization.—The work was in general charge of a superintendent, and, during the time it was being carried on at both ends, an assistant superintendent had charge at night. At each end there was a day and a night walking boss, who had general supervision of the men in the tunnels, the day walking boss being the superior, and responsible for the general conduct of the work at his end, both day and night. Two 10-hour shifts were worked, thirteen shifts every two weeks, no work being done on alternate Sundays and Sunday nights. With the exception of the walking bosses and the master mechanic, all the men changed from the day to the night shift every two weeks.

The organization was approximately as follows, for each shift:

General—Both Tunnels.

1 Master mechanic (days only),	1 Walking boss,
1 Machinist,	4 Locomotive engine runners,
1 Engine runner,	4 Brakemen,
2 Firemen,	1 Switchman,
2 Oilers,	1 Foreman on dump,
1 Electrician and helper,	6 Men on dump,
1 Drill machinist and helper,	1 Foreman on track,
3 Blacksmiths and helpers,	6 Men on track.
1 Powderman,	

In Each Tunnel.

Drilling and Blasting.	*Mucking.*
1 Foreman,	1 Shovel engineer,
12 Drillers,	1 Cranesman,
12 Helpers,	1 Muck boss,
1 Nipper,	12 Muckers.
1 Pipe-fitter.	

RECORDS.

The records of the work have been based largely on the reports of the day and night inspectors, which were made out on regular forms.

A daily report card was made out each morning and forwarded to the office of the chief engineer. It covered the work done for the previous 24 hours, up to 6 o'clock each morning.

A telephone report was made to the resident engineer by the inspectors each day at 8.30 A. M., giving the conditions, number of men, etc., at the opening of the day's work.

A daily progress profile, on 10 by 10 to the inch cross-section paper, covering the whole length of the tunnels, was kept in the office of the resident engineer. This was mounted in sections, on a piece of composition board, and hung on the wall for convenient reference. The information, showing the progress up to 6 o'clock each morning, was shown on the report of the night inspector, and was plotted on this profile at 7 o'clock each morning. The plotting was left in pencil, and each month's work was colored in. A progress profile was taken by the men of the alignment corps each Saturday morning and plotted by them, alternate weeks being in red and blue ink on the same profile.

A chart showing the number of drills working, time worked, blasting periods, etc. (Plate XLIV), was plotted each morning and was extremely useful, not only in keeping in touch with the work, but in compiling many of the statistics used in the preparation of this paper. These cross-section sheets were ruled 12 by 12 to the inch, thus giving one space per hour horizontally. In the top vertical space are shown the heading drills, their time of stopping and starting, and their number, each heavy line representing one drill. In the next space below are shown the drills on the bench, lift holes, etc.

The blasting time is shown by the portion hatched (shown in red on the original), which covers the whole vertical space when a com-

plete round of both heading and bench is blasted, and only part, top or bottom, as the case might be, if only one or the other. The number of drillers and muckers at the main working face is shown, and below that (in red ink on the original) the number of cubic yards handled each shift. The time the shovel is working is shown by the heavy line filling a whole space; and the air pressure, platted from the recording gauge charts, is shown in the space below.

A combination daily and weekly report, showing the total number of men working on each section, and the number of cubic yards excavated, was entered every day and kept on a filing board in the office of the resident engineer, and a copy was sent to the main office at the end of the week, with such notes on the back as might be necessary, or of interest.

A report was made out weekly and sent to the contractor's superintendent, showing any deviations from grade, any tight places, and the station of bench and headings.

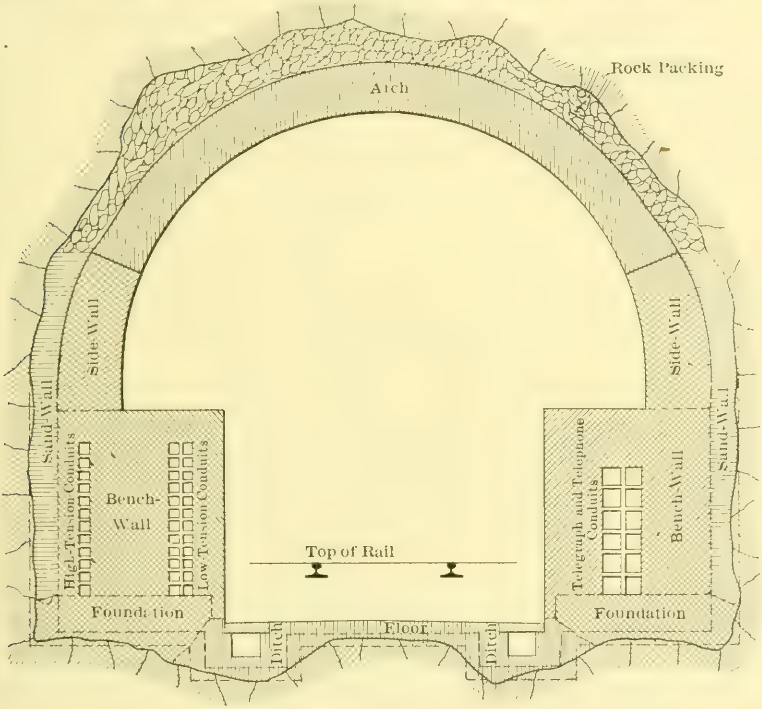
A monthly report was made to the chief engineer, giving detailed statistics of the amount of work done, etc., plant installed, and short notes of any matter of interest affecting the work in any way.

Tunnel Lining.

Preliminary Considerations.—For the placing of the concrete lining, a sub-contract was given to Messrs. King, Rice and Ganey, by Mr. Bradley, which provided substantially that all materials should be supplied by him, and delivered to the sub-contractors at track level, at or near the point in the tunnel at which they were to be placed, and that he would supply light and power; the sub-contractors were to supply the plant, forms, and labor necessary for placing the concrete and water-proofing, building the conduit lines, manholes, etc., etc., to complete the lining, the general form of which is shown on Plate XXXII of the paper by Mr. Jacobs, and in Fig. 10. The latter also shows the different sections into which the lining was divided for purposes of construction, and the nomenclature adopted for each. It may be noted, incidentally, that the cubic contents of the lining per linear foot of tunnel is almost exactly half the quantity excavated, out to the standard section lines, and as there was some excavation outside of these lines, all of which had to be replaced, the actual quantity of material which had to be brought back into the tunnel

was quite a little more than half the quantity taken out. It will be evident, therefore, that the question of transportation was an important one.

An essential part of the agreement with the sub-contractors provided that the operations incident to the placing of the lining should be carried on so as to provide at all times space for a single track of 3-ft. gauge, running through the work, and the necessary clearance



SKETCH SHOWING DIVISION OF LINING, FOR PURPOSES OF CONSTRUCTION, AND NAMES OF SECTIONS

FIG. 10.

for the locomotives and cars used in hauling out the muck. A clearance diagram of one of the dinkys used in the tunnels, and its relation to the forms used, is shown by Fig. 12 and also by Fig. 16, the 4-yd. Allison cars, used for handling the muck, taking practically the same width, although they were not quite as high. This requirement and the limited space available must be kept in mind in considering the design finally adopted for the forms and plant required in placing

the lining. It should also be kept in mind that, with the rolling stock used, there was only room for a single track through that part of the tunnel where any concrete had been built. As the concrete progressed, therefore, the length of single track was necessarily lengthened, and the problem of transportation was made increasingly difficult.

In working out a design for the bench-wall forms, another highly important and controlling factor, which had to be considered, was the arrangement of the conduit lines, as shown in the general cross-section.*

The quantities of the various materials in the lining, per linear foot of tunnel, were as follows:

Concrete		7.64 cu. yd.
Rock packing: Paid for	1.48 cu. yd.	
Outside standard section line	1.74 " "	
		3.22 " "
Iron and steel		44.2 lb.
Vitrified conduits		84.0 duct ft
Water-proofing		13.0 sq. ft.
Flags		3.3 " "

General Methods.—The lining was started at both ends of the tunnels before the headings were finally holed through, so that there was practically a separate organization at each end, each in charge of one of the members of the firm. The work at the Weehawken end was started first, and the plant and scheme of working adopted there was thoroughly tried out before the plant for the western end was built, consequently, the latter was somewhat more efficient, being designed in the light of the experience gained at the Weehawken end.

The general sequence of the plan first adopted in placing the concrete is shown by Fig. 10. The concrete was first placed in the foundations up to the elevation of the bottom of the conduit bines, this work, of course, being kept well in advance; next followed. in the order named, the sand-walls, water-proofing, conduits, bench-walls, and finally the arch. The foundation was built in any convenient lengths, multiples of 16 ft., the length of one section of form, the sand-walls in lengths of from 25 to 35 ft., the bench-walls in 25-ft. lengths, and the arch in 10-ft. lengths. Concrete was placed during the day shift only,

* Plate XXXII of the paper by Mr. Jacobs.

the forms being moved partly at night, and partly on the alternate days when concrete was not being placed in them.

Five gangs were organized at each end, the first placed concrete in the foundations in both tunnels, as the excavation was ready. In each tunnel there was a gang which built sand-wall one day and bench-wall the next, the two tunnels alternating so that only one bench-wall was built each day, and finally a gang in each tunnel building arches, a 10-ft. section being completed each day. During the night shift, the arch forms and travelers were moved, and all other forms, etc., were made ready for the concrete to be placed the following day. Some of the conduit laying was done by the night shift, but part of it was necessarily done during the day, as the concrete was built up. A small gang was kept busy in both tunnels, during the day shift, laying conduits and water-proofing. The latter two operations were generally performed by the same gang.

This organization, of course, required considerable regularity in the work, and this was finally attained, but at the beginning many sections were often not finished on time, thus creating considerable confusion. The progress possible with this organization (finally maintained with great regularity) was 75 ft. of bench-wall and 60 ft. of arch per week at each of the two working faces in each tunnel. This allowed the bench-wall to gain considerably on the arch, and therefore at a suitable point, as shown on the progress diagram, Fig. 9, a third pair of arches was started, one in each tunnel, increasing the progress on the arches to 180 ft. per week in each tunnel.

Mixing and Transportation.—All the concrete used on this section was mixed in Hains mixers, one being at each end. At the Weehawken shaft the mixer was installed in the framework supporting the head-house and elevators; and storage bins were arranged above, as shown by Fig. 11, *A,* the whole structure being somewhat strengthened to allow this to be done. At the western end the mixer was placed immediately under the bins of the stone crusher, as shown by Fig. 11, *B,* the track below being connected directly with the tunnels. The stone bin under the screen of the crusher plant at the Hackensack end was divided into three parts, the center being filled with sand by a derrick having a clam-shell bucket, the other two with stone directly from the screen above.

This type of mixer proved very efficient on this work. The largest

number of full batches (0.8 cu. yd.) mixed in one plant per hour was about 35; the largest number per day of 10 hours was about 240; but the apparatus was never worked to its full capacity, the quantity of concrete which it was possible to use being limited by other considerations.

The concrete for the foundations was hauled in steel, V-shaped, dumping cars holding about 1 cu. yd., and the concrete for the bench-walls and arches in Stuebner, 1-yd., bottom-dumping buckets placed on small flat cars, as shown by Fig. 1, Plate XLV. Rock packing was

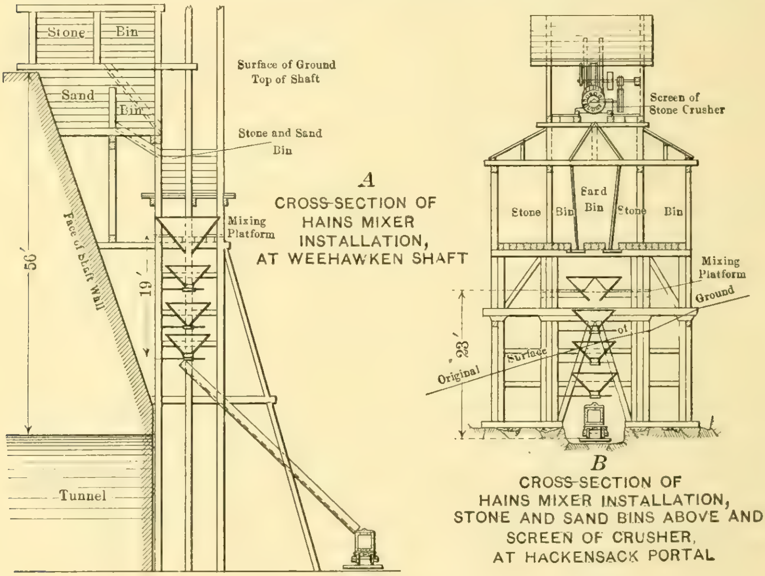


FIG. 11.

handled in Allison 4-yd. cars and also in the cars shown by Fig. 5, as well as in the Stuebner buckets, the latter, however, being most generally used. Mules were used for a short time at the Weehawken end to haul the concrete in, but proved entirely inadequate to haul the loaded cars up the 1.3% grade, and locomotives were substituted after the headings were holed through. At the western end the cars were allowed to coast in, and, up to the time the headings were holed through, were hauled back by mules; after that they were pushed out by a locomotive which had gone in ahead of them. As a rule, from 8 to 10 cars of concrete and rock packing were sent in, one after the other, in proper order, a boy riding on each car and stopping it at the proper place; all these cars were pushed out together when empty.

PLATE XLV.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
LAVIS ON
BERGEN HILL TUNNELS: PENNSYLVANIA RAILROAD.

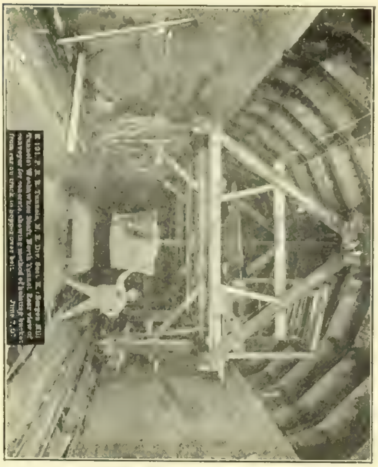


FIG. 1.

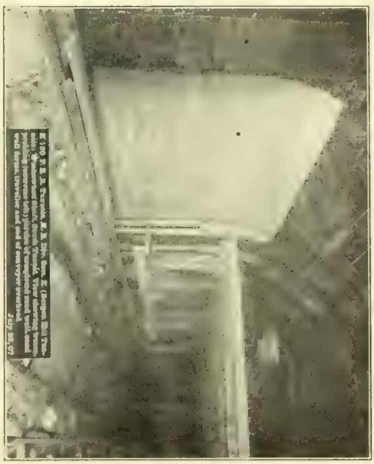


FIG. 2.

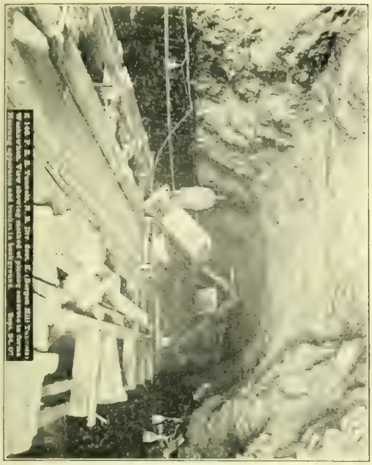


FIG. 3.

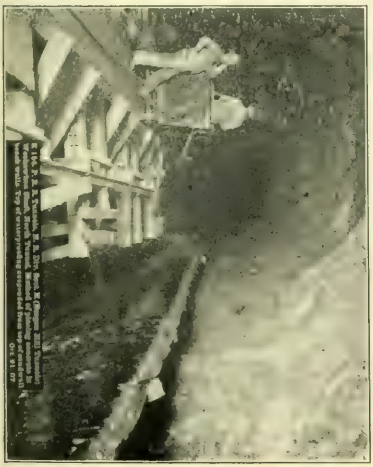


FIG. 4.

During the time the excavation was being carried on simultaneously with the lining at the Weehawken end, the rock packing was loaded at the working face and sent out to the point where it was to be used; after that the rock packing was sent in from outside from the reserve pile on the north side of Baldwin Avenue.

At the western end the larger part of the rock packing was sent in from outside, but occasionally, during the time the excavation was going on, the cars from the heading were stopped at convenient points, generally under the gantries, where the lining was being placed, and whatever stone could be utilized was sorted from the top and passed up to the platforms above.

After the headings were holed through, there was considerable difficulty at times in getting a sufficient supply of concrete and rock packing into the tunnel at the time it was required, and while undoubtedly the transportation facilities may have had some influence in this, the principal trouble lay in the difficulty of securing a sufficient supply of proper stone for rock packing, and for the crusher.

While the excavation was progressing, the cars of muck, as they came from the headings, were taken directly to the crusher and dumped into it, the proportion of fine material being fairly constant and the supply regular. At this time, also, a portion of the rock not required at the crusher was dumped along the edge of the bank on the south side of the approach, the larger stones rolling to the bottom where they were easily available to be loaded into cars for rock packing, being entirely free from the fine material; as this stone at the bottom of the bank was used up, the supply was renewed, the rock suitable for rock packing being automatically separated from the fine material as it rolled to the foot of the slope.

After the excavation was completed, however, it was necessary to go into the bulk of the storage piles to get material for the crusher and for rock packing, and then the difficulties were materially increased by the large quantity of fine material encountered, the proportion remaining after the rock packing had been sorted out being too large to send through the crusher. It was not only the handling over of this fine material which caused delay, but the difficulty of disposing of it. On rainy days the trouble was increased by the difficulty of getting men to work in the open.

The delays due to transportation were usually caused by derail-

ments, which were more numerous than they should have been, and were due to the condition of the rolling stock rather than to that of the track. These delays, especially when they occurred in the early part of the day, greatly increased the cost, by necessitating over-time work; a delay of 1 hour in the forenoon generally meant 2 hours' work after 6 o'clock to finish the day's work.

The average number of cars handled (round trips of 1 car) during a day (two 10-hour shifts) at the Hackensack end during January, 1908, when the excavation and lining were in full swing, was about 125 cars of muck and 200 cars of lining material, the former being hauled by locomotives and the latter by mules.

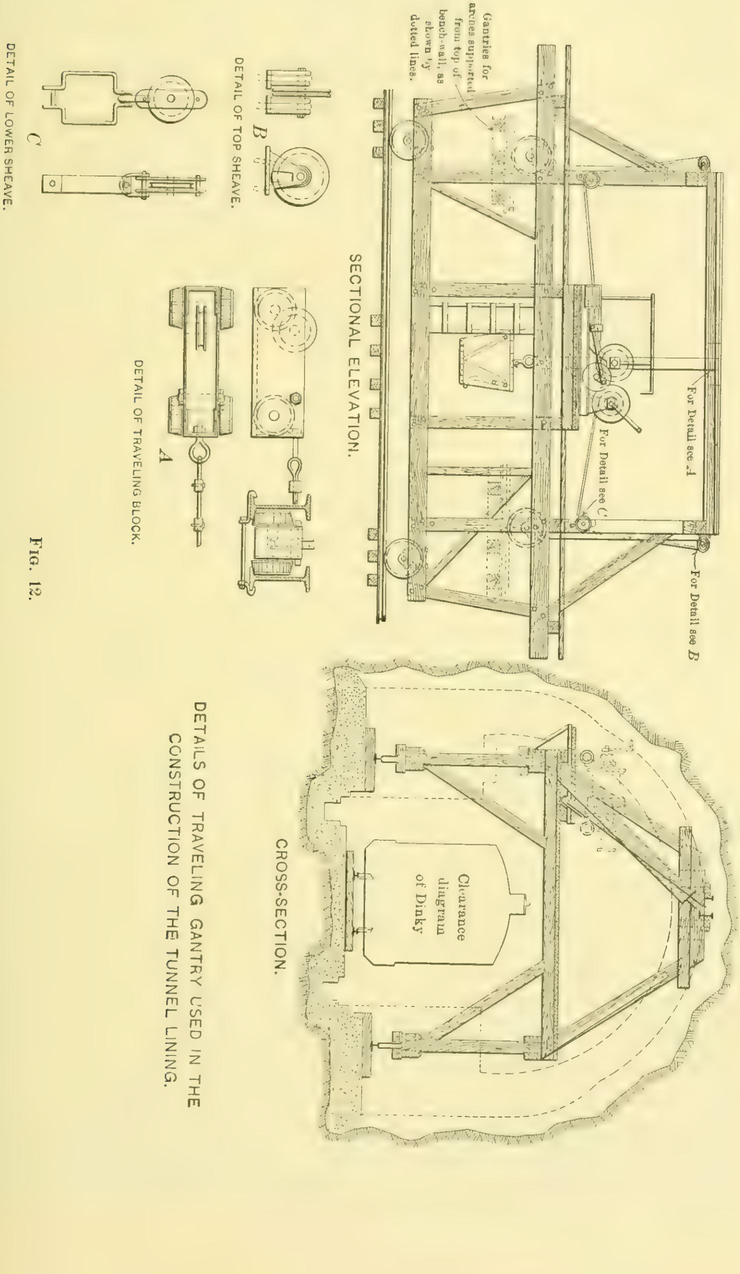
Methods of Handling Concrete in the Tunnels.—The concrete for the floor, ditches, and foundations, was brought into the tunnel in V-shaped steel, dumping cars, and dumped as near as possible to the place it was to occupy.

The concrete for the arches and bench-walls was loaded at the mixers into 1-yd., Stuebner, bottom-dumping buckets which just held a 4-bag batch. These buckets were placed on small flat cars, hauled into the tunnel, placed beneath the traveling gantry, as shown by Fig. 1, Plate XLV, and hoisted to the platform above.

These traveling gantries, the details of which are shown by Fig. 12, consisted essentially of platforms at each end of which an A-frame was erected; the latter supported at their apexes two I-beams, from the lower flanges of which was suspended a traveling block, shown at *A*, Fig. 12, and through which the hoisting rope was rigged. The buckets were hoisted through an opening in the platform and then moved along to where they could be dumped. The platforms were supported on wheels traveling on rails laid on the concrete of the foundation (for the bench-wall gantries) or on top of the bench-wall (for the arch gantries).

Each of the first two of these traveling gantries used was equipped with a belt conveyor working on a cantilever arm, as shown by Figs. 3 and 4, Plate XLII, and Figs. 1 and 2, Plate XLV. In using these belt conveyors, the concrete was dumped from the Stuebner bucket into a hopper, Fig. 1, Plate XLV, with an adjustable slot in the bottom, under which the belt ran.

It was the original intention, in designing the conveyor, that the end of the cantilever arm should be swung from one side of the tun-



DETAILS OF TRAVELING GANTRY USED IN THE CONSTRUCTION OF THE TUNNEL LINING.

FIG. 12.

nel to the other, and that the traveler should be moved backward or forward, as might be required, and thus deliver the concrete from the end of the belt directly over the place in which it was to be deposited in the bench-walls. As a matter of fact, it was found impractical in operation to move the gantry readily, owing to its great weight, which was supported on only four ordinary car wheels and their bearings, and it was found more convenient to leave the arm in one position near the center, letting the concrete drop on the platform above the bench- or sand-wall forms, whence it could be shoveled into place, than to attempt to move it as had been intended. Both of these difficulties might possibly have been overcome by modifications in the design of the gantry and conveyor, had this method of handling the concrete seemed otherwise desirable.

The principal difficulty with its use, however, was the inability to take care of more than one batch of concrete at a time. When one batch had been dumped into the hopper, a second could not be disposed of until the first had nearly all run through on the belt, and this took from 7 to 20 min., varying with the consistency of the concrete, etc. In a few instances, where there happened to be some fairly dry batches, the concrete could not be started through the slot at all, and had to be shoveled out of the hopper. On the other hand, it is stated that some batches, under favorable conditions, passed through in about 2 min., but this was quite exceptional, and the operation was irregular and uncertain.

Before the final method of handling the concrete was adopted, a trial was made of two forms of cars and buckets, to be used on the top platform, as shown by Figs. 3 and 4, and Plate XLV. In the method shown by Fig. 3, Plate XLV, the concrete was hoisted in the regular Stuebner buckets, one of which can be seen suspended in the background of this photograph, and dumped into the car shown, which was mounted so that it could be revolved in a horizontal plane. It was intended to move this car on the tracks to the point at which the concrete was required, and dump it directly through a chute into the bench-walls. This car was abandoned, as there was a great deal of difficulty in turning it when it was loaded, and in several instances it had to be dumped straight ahead in the middle of the platform and the concrete shoveled into the forms. This method was also objectionable when the bucket was dumped, inasmuch as the force of the impact

of a whole batch of concrete dumped from such a height into the forms, not only tended to throw the conduits out of line, and to break them, but also caused considerable strain on the forms.

The bucket shown by Fig. 4, Plate XLV, was next tried. It had a slanting bottom and a door opening at the side. It was filled at the mixer, came into the tunnel on a small flat car, and was hoisted and placed on a similar car on top, as shown. This bucket was not successful, as its great weight made it difficult to handle, and it generally required a man to shovel the concrete out, which latter, of course, had been pretty well compacted in the bottom of the bucket by its trip from the mixer. All these cars were hauled backward and forward on the top platform by a rope running to the winch on the hoisting engine on the traveling gantry.

Aside from the fact that neither type was a success, neither of these schemes was much improvement over the belt, inasmuch as only one batch could be handled at a time, owing to the necessity of using the engine to haul the cars back and forth on the platform. The final solution was found in the use of the traveling gantry, shown by Fig. 12 and Fig. 1, Plate XLVII, the latter being one of the arch gantries. The gantry used for the bench- and sand-walls was supported on framed bents on wheels running on rails laid on the foundation; that for the arch was the same, except that the high-framed bent was dispensed with, the side-sills resting directly on the journals of wheels traveling on rails on top of the finished bench-wall.

These gantries were used only as a means of hoisting the buckets and moving them along to where they could be dumped directly on the platform, whence the concrete was shoveled into wheel-barrows, which could be dumped directly into the bench-walls; or, in the case of the arches, shoveled from the platform of the gantry to the intermediate platform on the arch ribs, and thence directly into the arch. This use of wheel-barrows, though apparently a somewhat crude method and a retrogression from the use of the belt conveyor, proved very successful, and really involved no more labor than did the conveyors, although this might not have been the case had these latter worked as they were originally designed to.

The method finally adopted allowed as many as four buckets to be dumped on the platform on one end of the arch gantry at one time, and eight on one end of that used for the bench-walls, the workmen

handling about three of these latter into the forms by the time the last of the eight was dumped. It required about 1½ min. to place a car under the gantry, hoist the bucket, dump, close it, and return it to the car below.

Rock packing was stored at the other end of the platform, for use as required, when it was not handled directly from the end nearest the work. This method allowed the concrete and other materials to be brought in in trains at infrequent intervals, and provided a sufficient supply of material on hand so that the men handling it on top could be kept steadily at work.

Each hoisting engine on these gantries had 7 by 10-in. cylinders, and a double drum; some of them were Lamberts and some Mundys, operated by compressed air.

Ditches, Floor and Foundations.—The first method of building the foundation was that shown by Fig. 13, *A*; no attempt was then made to build the ditch, or floor, the intention being to leave these until the completion of the remainder of the lining. In building the bench-wall on this foundation, however, it was found difficult to secure the bottom of the forms properly (Fig. 2, Plate XLVI), so as to prevent any give, as the material under the track was not solid enough to brace against. It was decided, therefore, to build the whole of the ditch (see Fig. 13, *B*) so that the bottom of the forms could be braced against the solid concrete. At the beginning of the work, the face of the bench-wall was built up to the level of the bottom of the conduits with the foundation; if, therefore, in placing the concrete above this level, extreme care were not taken to get a tight fit between the bench-wall form and the lower face, and then to hold it rigidly in place, the result was a rather unsightly horizontal joint high enough to be plainly visible. The position of this joint may be seen in Fig. 2, Plate XLVI, which shows the first section of bench-wall built. Several subsequent sections showed an overhang above this joint, amounting in one or two cases to as much as ½ in., due to the fact that the bench-wall form moved or did not fit tightly. This defect was obviated by building the foundations with an offset on the face, shown by Fig. 13, *B*, so that the joint came at the level of the top of the flagging over the ditches, and therefore was almost entirely concealed; at the same time this allowed a sufficient surface, on the plane of the face of the bench-wall, against which the bench-wall forms could be braced and lined up.

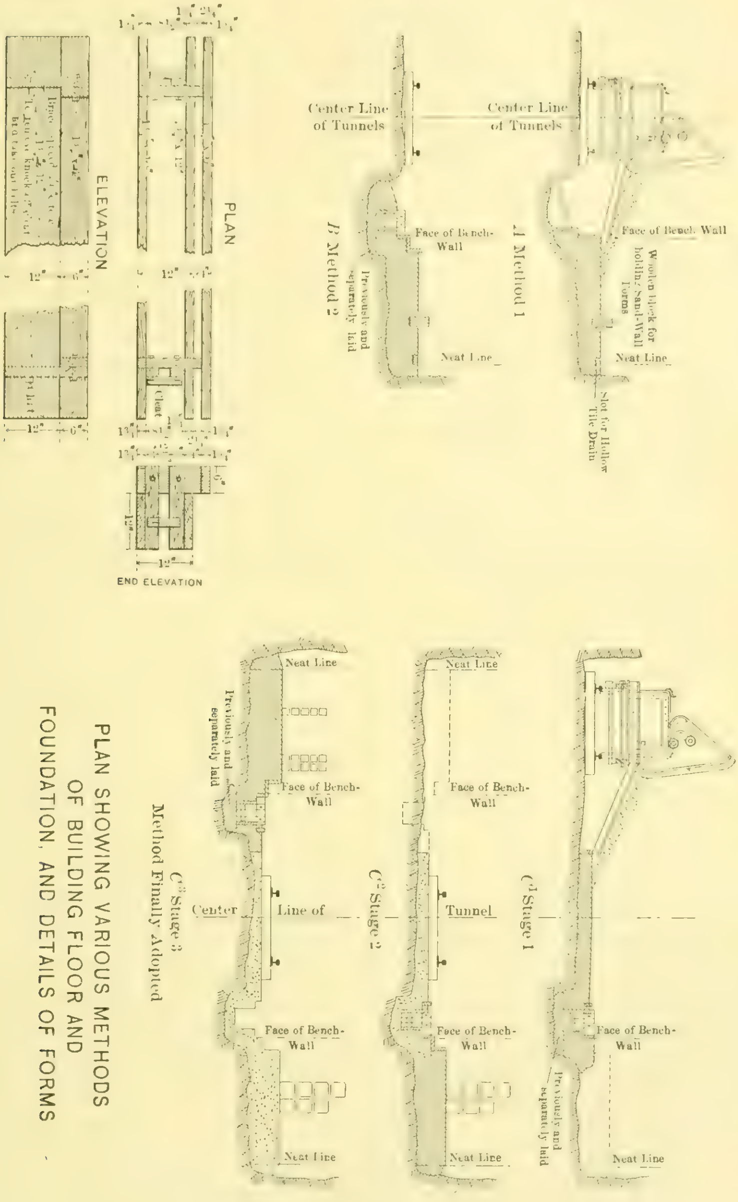


FIG. 13.

PLAN SHOWING VARIOUS METHODS OF BUILDING FLOOR AND FOUNDATION, AND DETAILS OF FORMS

The ditch forms were set very carefully to line and grade by the alignment corps, as this formed the starting point of all the rest of the work, the only other thing which was necessary was to give a level at the front end of the bench-wall form, after it was set, for the elevation of the top of the bench, and to check up the stations of the ends of the sections occasionally to see that they were at the even 25-ft. points (that is +08, +33, +58, and +83).

After a short length had been built with the ditches only, it was thought desirable to try and put in the floor as well, so that the whole of the concrete would be put in place as the lining advanced, and leave less cleaning up to be done over the end of a single track, in the restricted spaces between the bench-walls. Fig. 13, *C,* shows the method finally adopted. In this may be seen the three stages in which it was put in, the details of the ditch forms being shown by Fig. 13, *D.*

In that part of the tunnel where sand-walls were built, a hollow tile drain was built into the foundation, as shown in Fig. 13, *A* and *B,* along the foot of the water-proofing and connected at intervals with the drains by 4-in. cast-iron pipes. When the sand-walls and water-proofing were not built, however, the concrete of the foundations was sloped from the neat line back to the rock, as shown by Fig. 13, C^3, so that in case any water found its way down through the rock packing, its tendency would be to flow back against the rock, or to follow the low part of this concrete to 4-in. cast-iron pipes leading to the side ditches, rather than to find its way through the joint between the foundation and the bench-wall and so into the lower duct lines.

Sand-Walls.—The sand-wall forms first used are shown in Fig. 2, Plate XLV, with a section of the finished sand-wall. As this work was only intended to give a comparatively smooth surface against which to place the water-proofing, no particular care was taken with the surface, except to avoid sharp projections which might cut through the felt and pitch used for this purpose. A rather porous concrete (with all the rock which could be safely embedded in it and have the wall stand) was used, so that it would not act as a dam, but rather tend to allow the water to find its way to the bottom of the tunnel, and so into the drains.

The traveling gantry for placing the concrete in the sand-walls, as first designed, with the belt conveyor, could of course only deliver the concrete at one end. Before setting the forms for a new section, it

was necessary, therefore, to move the gantry ahead, before the cross-bracing between the tops of the forms, which also held the top platform, could be placed in position. Fig. 2, Plate XLV, shows the end of the conveyor over the top of the cross-braces. In order to hold the bottom of these forms, small wooden blocks were embedded in the foundation concrete, against which they could be wedged, as shown by Fig. 13, *A*; these blocks were cut out after the sand-wall had been built.

After the forms had been filled, the conveyor could not be moved back to the bench-wall until the concrete had set sufficiently so that these cross-braces could be removed, and, on account of the overhang at the top, the set had to be fairly good in order to prevent this overhang from breaking off. This arrangement, therefore, for placing the concrete was found to be impractical, if the proposed schedule of a section of bench-wall and a section of sand-wall to be built on alternate days, was to be carried out. In a few instances, where the sand-wall was finished fairly early in the afternoon, the forms were released next morning, and the conveyor was moved back, but, even then, 2 or 3 hours at least were lost at the beginning of the shift. The conveyor, however, was abandoned, for the reasons previously given, and the traveling gantry was rearranged to allow concrete to be delivered at either end; it was then only necessary to move it backward and forward between the bench- and sand-wall forms instead of through these forms. This permitted the construction of the much more substantial type of forms shown by Fig. 14.

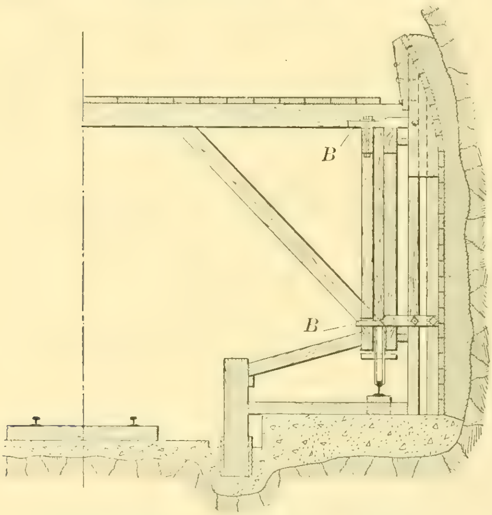
After being moved ahead on the track on top of the foundation, the form was first blocked up to grade, and then adjusted to line by the screws and slotted cleats shown at *B*, Fig. 14, after which it was secured by the braces from the ditches, as shown. The face lagging was placed in separate pieces and held against the uprights by lightly nailing every third or fourth piece; the whole was removed each time the form was moved, and built up again as the concrete was placed.

Considerable care was taken to slope the top of the sand-wall back toward the rock, as shown by Fig. 14, and to allow free drainage along the top (which ran parallel to the grade of the tunnel) to the 4-in. cast-iron drain pipes which carried the water from the rock packing above the arch to the drains beneath the track.

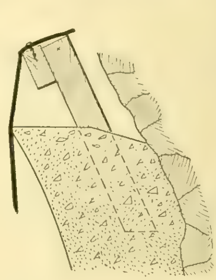
Sand-walls were built for a length of about 1 100 ft. in each tunnel at the Weehawken end, and about 700 ft. in each tunnel at the western

end, the remainder of the work, with the exception of a few short stretches, not being considered wet enough to require water-proofing.

Conduits.—The arrangement of the conduit lines is shown in the general cross-section.* On the core-wall side there are 48 lines for telegraph and telephone cables, built of 4-way multiple conduit, each piece of which is 3 ft. long and about 10 in. square outside. On the other side there are the high- and low-tension lines, built of single conduit 18 in. long and a little more than 5 in. square outside. Manholes or splicing chambers are built every 400 ft., and are about 8 ft.



TRAVELING FORM FOR BUILDING SAND-WALL



DETAIL SHOWING METHOD OF HANGING WATER-PROOFING FROM TOP OF SAND-WALL

FIG. 14.

long and 4 ft. wide. General views of the conduits as built are shown in Fig. 4, Plate XLVI, which shows all the lines in one tunnel, and in Fig. 1, Plate XLVI, which shows the telegraph and telephone lines, with the expanding mandrels used in laying them.

In attempting to plan the work of placing the lining, two methods of building the bench-wall were considered. One was to build the wall in longitudinal sections, each section separated by a line of ducts; and the other was to attempt to build the wall in the manner called for by the specifications, which required the concrete to be carried up in layers as the conduits were laid. In this latter method, it was

* Plate XXXII in the paper by Mr. Jacobs.

PLATE XLVI.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
LAVIS ON
BERGEN HILL TUNNELS: PENNSYLVANIA RAILROAD.

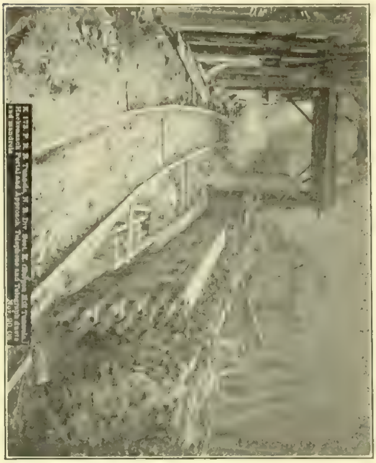


FIG. 1.

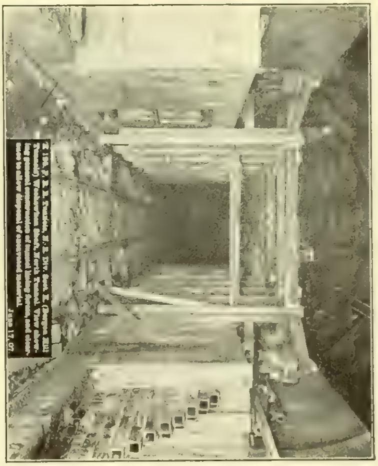


FIG. 2.

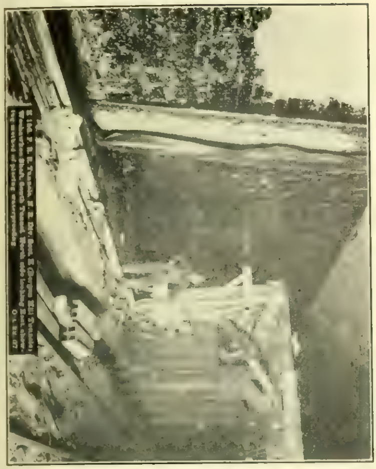


FIG. 3.

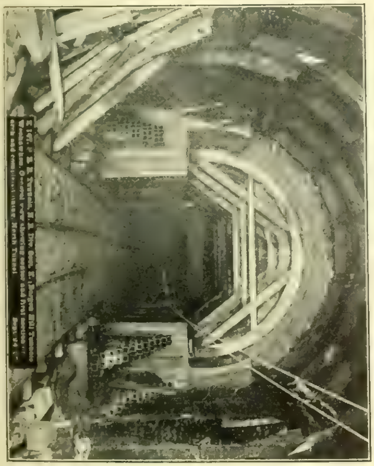


FIG. 4.

proposed to bond the concrete together with the forked bonds, the details of which are shown by Fig. 15, *A*, but, as it might have been impractical to use these if the wall had been built in sections, provision was made in the contract to place expanded metal, as shown by Fig. 15, *B*, if this was thought advisable. The method of construction necessary, if the wall had been built in sections, is shown graphically by the five sketches, Fig. 15, *B*, 1, 2, 3, 4, and 5.

The form and details of the expanding mandrel which was finally designed to meet the conditions, and proved so satisfactory in every way, are shown by Fig. 15, *C*. The mandrel consisted of two triangular pieces of hard pine, separated by wedges attached to one piece which fitted into slots in the other; these, when expanded, practically filled the whole of the inside of the ducts. One of these mandrels was placed in each line of single ducts and two in each 4-way duct, placed diagonally, as shown in Fig. 1, Plate XLVI. This required 60 mandrels at each working point, or 240 for the whole work. The mandrels were 35 ft. long, so that they easily covered the whole of a 25-ft. section, projected sufficiently far back into the previously finished work to assure the continuity of the alignment, and allowed the ends to be racked out at the forward end to secure proper breaks between the joints.

In laying the single conduits, as a rule, the (collapsed) mandrels were pulled ahead from the previous section as each line was laid, and the conduits were strung on it until the whole length was completed; the conduits were then pushed up tight together, so as to close the joints as tightly as possible, and then the mandrel was expanded. The conduits were thus held firmly in position, and the forward end of the line was lifted slightly so that the wraps could be placed around the joints. The 4-way conduits were generally laid in the ordinary way, except that no laying mandrel was necessary. One dowel was used between each of the pieces of conduit, at the center, and the joints were wrapped. When a line was finished, two mandrels were placed diagonally in each line and expanded simultaneously, so that any inequalities in the ducts themselves were divided as far as possible. In connection with the use of these mandrels, one of the points which was most carefully watched was that they projected back into the last completed section, thus insuring the continuity of the alignment.

It was originally intended to wrap the joints of the 4-way ducts

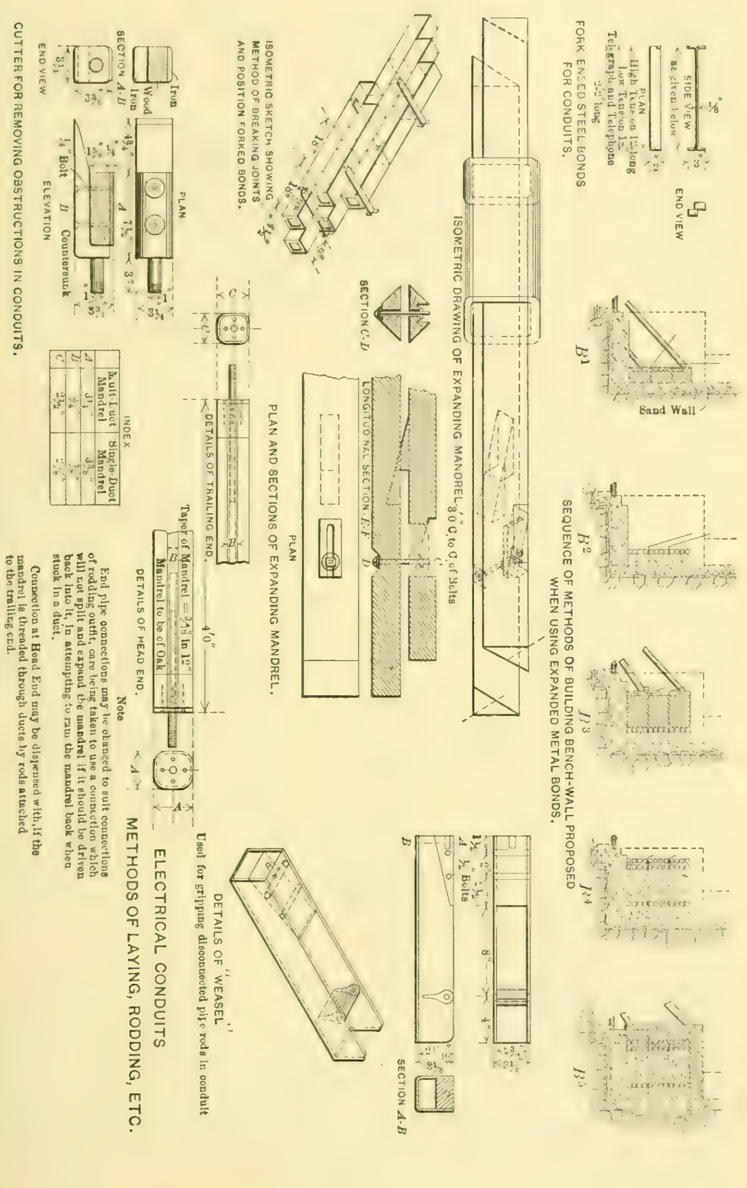
only, but it was found to be impractical to keep the grout from the wet concrete entirely out of the single ducts, and, after a short trial, it was decided to wrap these also. The expanding mandrel kept out a great deal of the cement, and, in the sections laid without wraps, the only difficulty from this cause seemed to be that a slight film of grout, from $\frac{1}{16}$ to $\frac{1}{8}$ in. thick, was deposited on the bottom of the inside of the ducts at some places, and although this was not considered a serious defect, it was thought that the slight extra cost of placing the wraps would undoubtedly be justified by the practically perfect results obtained by using them.

Considerable attention was given to breaking the joints of the ducts properly, so as to maintain throughout the conduit lines the greatest break possible. The joints in each superimposed line were broken at half the length of the individual pieces of conduit, the joints in lines in the same horizontal plane being broken at one-quarter the length, thus preventing any joints from touching one another either at the sides or corners, which tended to prevent a burn-out on one line from being communicated to another. There was some little difficulty at first in maintaining the breaks, owing to slight variations in the lengths of the conduit, but after a very short time both the workmen and the inspectors became very expert at this and in the proper use of short lengths to maintain the spacing; after the first few weeks there was little if any difficulty in attaining at all times almost perfect results. The method of making the breaks is shown in the photographs and by the isometric sketch at *F*, Fig. 15.

All the conduits used on this work were furnished by the Great Eastern Clay Company, and were made at its factory at South River, N. J., where they were inspected before shipment.

The mandrel used in the final rodding was made as shown at *G*, Fig. 15, the larger size being used for all lines. The rods for pushing it through the conduit lines were made of $6\frac{1}{2}$-ft. lengths of ordinary 1-in. wrought-iron pipe with extra long (3-in.) couplings. The lines were rodded in both directions from alternate manholes, thus avoiding uncoupling the rods and allowing every pull to be effective in pushing the mandrel through the ducts.

Wooden rods were used at first, but proved entirely too light, as the mandrels used were a close fit, and it required considerable effort to push them through 400 ft. of conduit. Iron pipe with ordinary couplings



DETAILS OF FINAL RODDING MANDRELS.

FIG. 15.

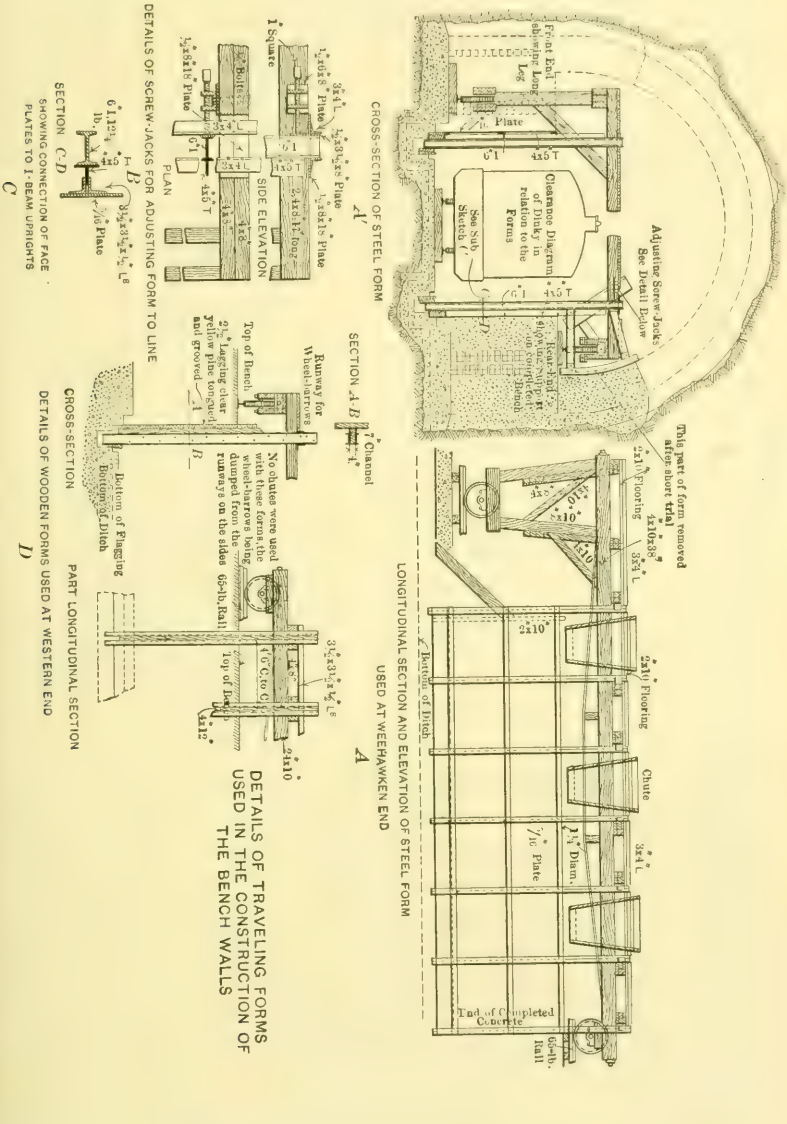
was next tried, but the couplings broke quite often as the threads became worn in uncoupling the sections to move the rods from one line to another, and the break was generally inside a duct line. The long couplings were finally adopted, and a set of rods was put in each line, that is, six sets in all, so that when coupled up they remained in the line until it was finished. The expense of the extra quantity of pipe thus required was more than offset by the decreased labor cost.

It was thought necessary at first to run a cutter, Fig. 15, *E*, through the conduits ahead of the final rodding mandrel, but this was soon found to be unnecessary except in a very few instances, and, after a short experience, the cutter was only used at places where an obstruction was encountered by the mandrel.

At such times as the pipe became uncoupled inside the duct line, the part remaining inside was recovered by the use of the tool shown at *D*, Fig. 15, called a "weasel." In two instances, the mandrel became stuck in such a manner that the duct line had to be cut into in order to take it out.

The best day's work of the rodding gang (1 foreman and 4 men) was 20 400 duct ft. of the 4-way conduit in the telegraph and telephone line, and 19 200 duct ft. of single conduit on the low-tension line, an average day's work under ordinary conditions being about 10 000 duct ft. The cost, including labor, material, and all tools, for rodding for the whole work was slightly less than 0.2 cent per duct ft. The average cost of the single conduit was about 0.25 cents per ft., and of the 4-way, 0.15 cents per ft. About 10% of the conduit lines were rodded twice, owing to partial sections having been rodded once before completion. The best continuous work on rodding was done between October 22d and 29th, 1908, when in 7 working days, 105 600 duct ft. were rodded, an average of a little more than 15 000 ft. per day.

Bench-walls.—The original design for the tunnels provided for the construction of a brick arch above a point 22° above the springing line, that is, the part above the side-walls (Fig. 10). It was thought desirable, therefore, in designing the bench-wall forms, to provide for placing the concrete in the side-walls and bench-walls at one operation. These forms, as first designed, are shown by Fig. 2, Plate XLVI, and the details in Fig. 16, *A* and *A′*; they were built of steel, the facing plates being $\frac{5}{16}$ in. thick, in pieces 4 ft. 6 in. wide, and in length about 6 in. more than the height of the bench-wall.



DETAILS OF TRAVELING FORMS USED IN THE CONSTRUCTION OF THE BENCH WALLS
CROSS-SECTION OF STEEL FORM
LONGITUDINAL SECTION AND ELEVATION OF STEEL FORM USED AT WEEHAWKEN END
A
A'
Front End showing Long Leg
Plate
4x5 T
Clearance Diagram of Dinky in relation to the Forms
See Sub Sketch C
Adjusting Screw-Jacks See Detail Below
Rear End showing Support on Completed Bench
This part of form removed after short trial
2x10 Flooring
4x10x38"
3x4 L
2x10"
Chute
3x4 L
1¼" Diam.
7/16" Plate
End of Completed Concrete
65-lb. Rail
Bottom of Ditch
DETAILS OF SCREW-JACKS FOR ADJUSTING FORM TO LINE
SIDE ELEVATION
PLAN
1" Square
Bolts
SECTION C-D
SHOWING CONNECTION OF FACE PLATES TO I-BEAM UPRIGHTS
C
SECTION A-B
7" Channel
Runway for Wheel-barrows
Top of Bench
2½" Lagging clear yellow pine tongued and grooved
No chutes were used with these forms, the wheel-barrows being dumped from the runways on the sides
65-lb. Rail
4'0" C. to C.
3¼x3¼x¼ L8
4x12"
2x10"
CROSS-SECTION
PART LONGITUDINAL SECTION
Bottom of Flagging
Bottom of Ditch
B
D
DETAILS OF WOODEN FORMS USED AT WESTERN END

FIG. 16.

The design was controlled very largely by the necessity of providing the requisite clearance for the locomotives and muck cars, and the principal feature was the support of the forms on two trusses, one at either side, the front ends of which were supported from the foundation on a long leg, as shown in Fig. 3, Plate XLVI, and the rear ends directly on the journal-boxes of wheels traveling on a rail on the top of the finished bench, as shown in Fig. 2, Plate XLVI.

Although it had been decided to substitute concrete for brick in the arch before any of the lining was actually placed, two sets of forms for the Weehawken end had already been ordered and delivered, so it was decided to use them as designed, and place the side-wall with the bench.

The forms were designed so that 30-ft. lengths could be built, and this was done at the start, but owing to the occurrence of the refuge niches, ladders, etc., at 25-ft. intervals, it was soon seen that it would be advisable to build the bench-wall in sections of that length (25 ft.), or multiples of it, and as the clearance conditions seemed to preclude the possibility of making the forms 50 ft. long, 25 ft. was adopted. This permitted the removal of one of the panels, 4 ft. 6 in. wide, and at the same time it was decided to remove the side-wall forms. This decreased the load on the trusses considerably, but being still a trifle weak, they were strengthened by the substitution of 1¼-in. truss rods instead of the ¾-in. rods used originally. The top platform and the cross-bracing were also stiffened a little and tightened up to prevent racking.

The construction of the side-walls in conjunction with the bench-wall was abandoned for three reasons: First, it was found that there would be a much more even distribution of the work by including the side-wall with the arch rather than with the bench; second, there was difficulty in getting a good finish for the top of the bench-wall, as of course a top form for the latter had to be placed to prevent the concrete from squeezing up when the side-wall was built above it, which prevented troweling; the third reason was the weakness of the whole form as designed, and the increasing difficulty of adjusting it to line as the work progressed, the principal difficulty being with the curved side-wall forms.

The bench-wall forms were set in position, after they had been moved ahead, by first blocking the bottom against the face of the

foundation, as shown by Fig. 13. As previously noted, this foundation face had been built very carefully to line. The back end of the form, of course, was blocked tightly against the end of the previously finished section, and the top was made plumb by the adjusting screw-jacks shown in Fig. 16, *B*. At first these screws were $\frac{3}{4}$-in., but they were afterward changed to $1\frac{1}{4}$-in. The only points which it was necessary for the alignment corps to give in setting these forms was a grade at each of the front ends for the top of the finished bench.

The steel face forms in both tunnels gave excellent results, as far as smoothness of finish was concerned, but, owing to the imperviousness of the steel, small air holes were formed in the surface, though not in sufficient numbers or size to cause trouble or disfigure the work in any way.

The design of the bench-wall forms used at the western end, where this differs from the steel form, is shown by Fig. 16, *D*. The principal features in which they differed from those used at the Weehawken end was in the substitution of $2\frac{1}{2}$-in. tongued and grooved hard pine for the face. This timber was of the very best quality obtainable, each piece being especially selected and as nearly clear and free from knots or other defects as it was possible to get it. The edges of each piece were planed at the back so as to insure a tight joint on the face, and all joints were shellacked. These forms were used, without renewal of the face timber and with only two planings, for a length of 2 500 ft., or 100 separate sections, and gave good satisfaction.

In order to obtain a surface to which the face lagging could be fastened, wooden uprights were used and were reinforced on either side by light channels bolted together through the timber, in place of the I-beams used on the steel forms. The lagging was nailed to these uprights by 6-in. wire nails driven through the top edges of each piece as it was placed in position, thus leaving the surface entirely clear and free from any marks or nail holes, and in condition for planing when this became necessary. Runways for wheeling the concrete were built one either side over the bench-walls instead of having a center platform with chutes, as was used at Weehawken.

When the original lagging had become too much worn for further use, it was resurfaced with strips of $\frac{7}{8}$ by $2\frac{1}{2}$-in., clear, tongued and grooved, hard pine, placed vertically, which did fairly well and lasted to the end (about 1 000 ft.), although it was not altogether satis-

factory, and the last eight or ten sections built had to be rubbed down with a wooden float in order to obtain a suitable finish

In designing the forms for all exposed surfaces in the tunnels, it was the desire of the contractors to obtain directly from them a surface which would be satifactory to the engineers without further finishing than the patching of minor defects. In this they were generally quite successful, and excellent results were obtained, as shown in the view of the finished tunnel, Fig. 2, Plate XLVIII. The surface of the bench-walls was obtained solely by spading the face with a flat spade as the work progressed. No after treatment was resorted to, except for the few sections where the forms became worn. The top of the bench-wall was finished with a float about 2 or 3 hours after the concrete was placed.

When the work was well organized, a bench-wall was built at each end each day, one day in the North Tunnel, and the following day in the South. During the time sand-walls were being built, a sand-wall and bench-wall were built on alternate days in each tunnel, care being taken that when a bench-wall was being built in one tunnel, the sand-wall was being built in the other, this being necessary in order to equalize the work of the night gang and the conduit layers as well as the transportation.

The conduit layers on the day shift, two or three men and a foreman, required about 2 hours in the forenoon and 1 hour in the afternoon to lay their portion of the conduits, and usually finished this work by 3 P. M. At other times during the shift they were utilized at those points where rock packing was heaviest, and when the packing was brought in in the large cars, as shown in Fig. 1, Plate XLVII, these men helped unload it so that the track could be cleared as soon as possible. When water-proofing was to be done, the number of men in this gang was increased, so as to enable them to do that work also.

A gang of four rough carpenters and a foreman was employed on the day shift; they moved and set the bench-wall forms or sand-wall forms, as the case might be, and moved the traveling gantry into position. This was done in the afternoon, and required about 3 hours. They also took out, cleaned, repaired, and set all ditch forms, all passenger forms, circuit-breaker forms, and did all other repair work. The ladder forms, the refuge-niche forms, and overhead conductor

Fig. 1.

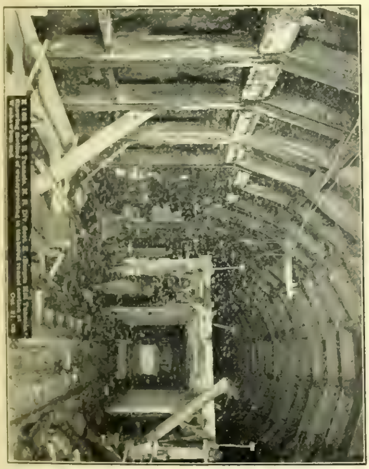


Fig. 2.

pocket forms were attended to by one man, who set, removed, cleaned, and repaired them. The carpenters on the night shift set the arch centers and gantries, also the manhole forms when needed. The conduit layers on the night shift laid up half the 4-way conduits (3-high) and one-third of the single ducts (4-high). This one gang laid the conduits in two sections of bench-wall each night, that is, one section at Weehawken and the other at the western end.

In concreting the bench-walls, the concrete was first placed on the side containing the single conduit until it reached the top of the four tiers laid, then the concrete gang was turned over to the side with the 4-way conduits while four more tiers of single conduits were laid, the work thus progressing, the conduits being laid on one side while concrete was placed on the other. On the side of the 4-way conduits the concrete was built in two layers while that on the side of the single ducts was built in three; the interval between the different layers was not sufficiently long to prevent a complete bond being obtained, and there were only one or two instances where there was any mark on the face to indicate a break.

After the work had been in progress some time, it was found to be quite feasible to build all the 4-way conduits at night and half the single conduits, that is, 6 ducts high, as the mandrels proved amply sufficient to hold them in place; in fact, had it been necessary, the writer has no doubt that all the ducts might have been laid and held in place with very little extra precaution, by the use of the expanding mandrels, as described under the head of conduit laying. A V-shaped joint about ½ in. deep was made between each section of bench-wall so that the expansion cracks would follow this joint rather than show irregularly on the face. These joints divided the face into the even 25-ft. panels, and were very effectual in concealing what few cracks there were.

After the construction of the sand-walls was discontinued, the space behind the bench-walls, between the neat line and the rock, was filled with rock packing, which was generally built, part way up at least, as a dry wall ahead of the construction of the bench-wall, or it was put in place simultaneously with the concrete, care being taken to keep it as free as possible for the drainage of any water there might be. Toward the latter part of the work, owing to the difficulty of getting sufficient rock packing during the day, a rough back form

for the bench-wall was built at the neat line, in places where the section was at all large, and the space was filled with rock afterward, generally at night or on Sundays.

In the sections where water-proofing was required, where no sand-wall was built, the rock was taken out for 2 ft. outside the neat line, if the excavation was not already that far out (at the expense of the contractors, who preferred to do this rather than build the sand-walls for the short sections required), so that there would be sufficient room for placing the water-proofing on the back of the bench-walls, as shown by Fig. 18, *E*. The water-proofing of these sections was left until just before the arch was to be built, and after being placed it was protected by a single row of brick laid on edge before the rock packing was filled in.

Arches.—The centering used for the arches is shown very clearly in Fig. 4, Plate XLVI, which is a view of the back end of the first section built at Weehawken. In this part of the tunnel, the lower part of the arch, about 5 ft. above the bench-wall, was built first, as previously referred to, but the centers, as will be seen, were built so that they could be used for the whole of the arch. The forward bulkhead, and the shoveling platform on a section being built, are shown in Fig. 3, Plate XLVII.

The front bulkheads used were made in nine sections, bolted to a $2\frac{1}{2}$ by $2\frac{1}{2}$-in. angle bent to the radius of the arch, as shown in Fig. 3, Plate XLVII, and fitting on the end of the lagging; when set they were braced partly against the rock of the roof and partly against the gantry. After the ribs and part of the lagging had been set by the night gang for a fresh section of arch, the braces holding the bulkheads were knocked out, the concrete placed during the day having set sufficiently by this time; the whole of the bulkhead was then easily moved ahead, sliding along the lagging to the forward end, and made ready for the next day's work. The middle section at the top was taken out temporarily, to facilitate working at the sides, until it was needed.

The traveling gantry used in handling the concrete for the arch is shown in Fig. 1, Plate XLVII, which also shows the form for the circuit-breaker chamber, and a car of rock packing on the track beneath.

The arches were built in 10-ft. sections, the ribs being spaced 5 ft. apart, the end ribs of each section supporting the end of the lagging

on two adjoining sections. Five sets of lagging and ten ribs were used at each place where the arch was being built, thus giving each section practically 4 days' set before removing the centers. Probably in the greater part of the work the centers could have been removed in from 40 to 48 hours after the concrete had been placed, but 3 days was considered the least time which would certainly be safe at all times, and the contractors thought that the very slight additional expense involved in leaving the centers up 4 days was more than warranted by the additional feeling of security.

The lagging was made from 3 by 6-in. clear, hard pine, 10 ft. long, dressed to about $2\frac{1}{2}$ in. in thickness, about $5\frac{1}{2}$ in. in width, and the sides to radial lines. As it was placed, every third or fourth piece was lightly nailed to the ribs; when the latter were released and taken down, the nails pulled out, and the lagging was left in place until one piece was pried out, allowing the others to fall. A light **A**-fame, about 8 ft. long, spanning the bench-walls, was placed below, in order to break the fall and allow the lagging to slide to the top of the bench-walls rather than fall to the track beneath.

Cross-passages between the two tunnels were built every 300 ft., their form being shown on Plate XXXII of the paper by Mr. Jacobs. There were two circuit-breaker chambers, one at Station 286 and the other at Station 310. Steel doors are provided so that all the openings between the two tunnels can be closed. At Station 294+24, the core-wall broke through for a length of about 40 ft., and instead of filling this in, a storage chamber 34 ft. long and 11 ft. wide, inside, was built there, the form for which is shown in Fig. 2, Plate XLVII. This photograph, as well as Fig. 1, Plate XLVII, a form for a circuit-breaker chamber, shows the method of setting the steel doors in the forms, so that they were built into the concrete instead of being fastened in with expansion bolts afterward, thus showing a perfect fit and a much neater job.

During construction the arches in each tunnel were kept even with each other, so that when the cross-passages were reached, they, and the sections of arch which they joined, could be completed at one operation.

By the methods used on this work, one section of arch was easily built in a shift, so that the monolithic construction of each section was easily secured, and concrete, as wet as it was possible to handle with

shovels, could be used for all except the last 5 ft. or so at the top, thus getting a structure which was as nearly impervious as possible under the circumstances.

The gangs placing the arches were paid over-time when they were required to work after 6 o'clock to finish their section, which was generally only necessary when the quantity of rock packing to be placed was very large. If they finished their section before 6 o'clock, however, they were allowed to quit when this was done, and were given a full day's pay. The difference in time, when there was any, was usually due to the greater or less quantity of rock packing, as the excavation varied from the standard section line.

In building the arches, the night gang set the two ribs (one at the center and one at the forward end of the section to be built), placed the lagging on the sides, 4 or 5 ft. high, built the shoveling platform on the horizontal cross-braces of the ribs, and placed the traveling gantry in position for use. The forward end of the gantry (that is, the end farthest from the arch being built), as shown in Fig. 1, Plate XLVII, was loaded with rock packing to be used as required. As the concrete was brought into the tunnel it was hoisted and dumped on the end of the gantry next the arch, and shoveled from there to the platform on the ribs and from there into place. The rock packing brought in during the day was dumped on the front or back end of the gantry, as was most convenient, and handled into the work in the intervals between batches of concrete. The concrete and rock packing, with the back-lagging and water-proofing, where these were used, were placed simultaneously, or nearly so, and brought up the sides together until the key was reached; the latter was then worked from the back toward the front. The key was usually made about 5 ft. wide, the lagging for this width was made 5 ft. long and put up in two sections. It was found to be more convenient to have the key of this width than narrower.

The method used in making the closures where two sections of the arch came together is shown by Fig. 17.

Water-proofing.—As already pointed out, the original design for the lining of these tunnels provided for a brick arch. It was intended to cover this arch with water-proofing, this latter extending over the whole of the roof and down the sides as far as the bottom of the conduit lines. The water-proofing was to be placed against the sand-

walls on the sides, up to the top of the side walls, Figs. 10 and 14. Over the arch, after being placed, it was to be protected by an armor course of brick, laid flat, the space between the brick and the excavation, which was required to be not less than 4 in. (and, as a matter of fact, was actually a great deal more), being filled with rock packing. Besides filling the space, this latter was designed to allow any water from the roof of the tunnel to find its way easily to the top of the

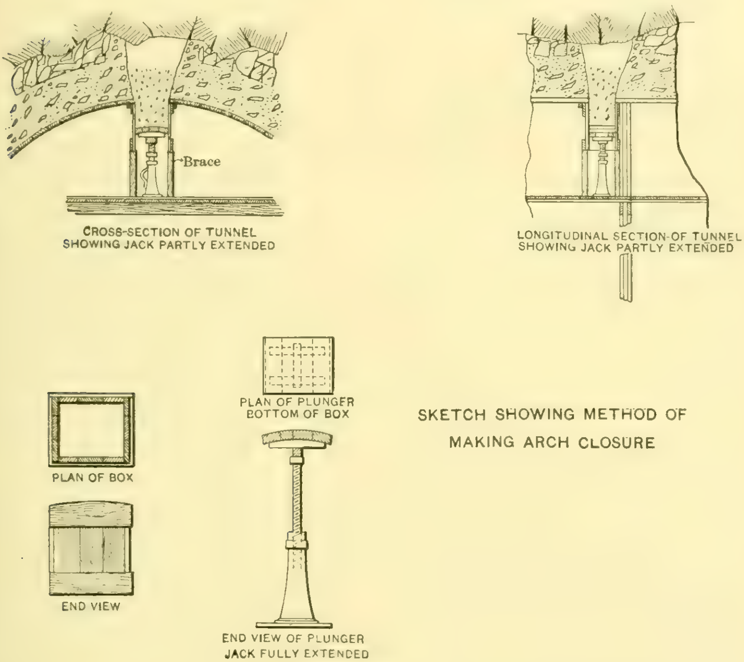


FIG. 17.

sand-wall, from there being carried through the 4-in. cast-iron pipes, shown on Plate XXXII* to the side ditches in the floor of the tunnel.

All the water-proofing placed in these tunnels was of felt and pitch, six-ply felt and seven layers of pitch. The felt was required to be Hydrex, or of equal quality, and the pitch, "Straight run coal-tar pitch which will soften at 60° Fahr., of a grade in which the distillate oils will have a specific gravity of 1.05."

In addition to tests as to the above qualities, the pitch was analyzed

* Of the paper by Mr. Jacobs.

to determine the amount of free carbon it contained, and was not accepted if this fell below 20 per cent.

It was considered quite important that there should be absolutely free drainage on the outer side of the lining, so that there would be no chance for any water to acquire a head. More than three-quarters of the length of these tunnels is below the level of mean high water, and while it was hardly expected that there would be any direct connection between the water in the Hudson River and the ground-water of the section penetrated, it was thought wise to provide ample drainage.

Before the lining was started, however, the excavation had progressed sufficiently to show that the tunnels, while very wet in places, and varying from that to quite damp, would be, on the whole, much dryer than had been anticipated. It was then decided to substitute concrete for the brick in the arch and omit the water-proofing over the top, except at places where water came into the tunnels in sufficiently large quantities to form practically a continuous stream. Three general types of construction for the arch were decided on, as shown in Fig. 18. The first, as shown at *A*, was to be used where the tunnel was quite dry. In this type, the sand-wall was omitted entirely, and the concrete and rock packing were built up together, the rock packing impinging to a certain extent on the concrete, and the concrete squeezing somewhat into the rock packing, as shown by Fig. 4, Plate XLVI. The section shown at *B* was used where the tunnels were damp, or where there were slight droppers not forming a continuous stream. The back lagging, of 1-in. boards, which was left in place, provided a practically smooth outer surface on the concrete arch, and allowing the concrete and rock packing to be built almost simultaneously. It was considered that the free drainage through the rock packing, the surface of the boards, and the smooth outer surface of the concrete in the arch would allow the comparatively small quantity of water in these parts of the tunnel to find its way to the sides, and thence to the ditches at the bottom, rather than to percolate through the concrete, and this proved to be very generally the case, as is shown by the dry condition of the tunnel as built. The back lagging was used over the arch, both where the sand-wall was built and where it was omitted, as well as being placed over the water-proofing of the arch as an armor course where water-proofing was required. Where the sand-

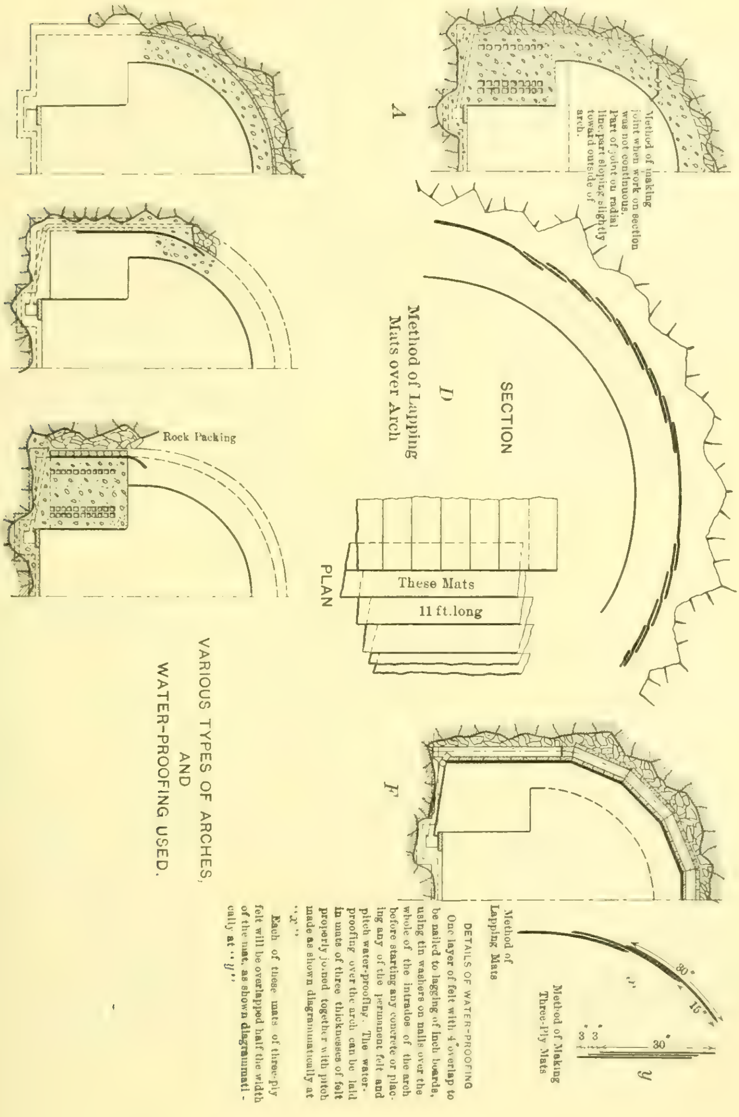

A
Method of making joint when work on section was not continuous. Part of joint on radial line, part sloping slightly toward outside of arch.
B
C
SECTION
D
Method of Lapping Mats over Arch
PLAN
These Mats
11 ft. long
Rock Packing
E
F
Method of Making Three-Ply Mats
80"
16"
30"
3 3
"x"
y
Method of Lapping Mats
DETAILS OF WATER-PROOFING
One layer of felt with 4" overlap to be nailed to lagging of inch boards, using tin washers on nails over the whole of the intrados of the arch before starting any concrete or placing any of the permanent felt and pitch water-proofing. The water-proofing over the arch can be laid in mats of three thicknesses of felt properly joined together with pitch made as shown diagrammatically at "x".
Each of these mats of three-ply felt will be overlapped half the width of the mat, as shown diagrammatically at "y".
VARIOUS TYPES OF ARCHES, AND WATER-PROOFING USED.

Fig. 18.

walls were built and water-proofed, and where the water-proofing was not carried over the arch, the water-proofing was turned in at the top, as shown at *C*, Fig. 18.

The third method provided for water-proofing the whole of the arch, and was the same as *B* except for the addition of the water-proofing inside the back lagging. In placing this water-proofing, the felt was cut in strips about 11 ft. long (about 1 ft. longer than the length of a section of arch), and six thicknesses were cemented together with hot pitch. These mats were then laid shingle-fashion, as shown at *D*, Fig. 18, up the sides of the arch until a space about 5 ft. wide remained at the crown; shorter mats were then brought out over this, laying them perpendicular to the axis of the tunnel. Care was taken in making all laps, irrespective of the direction in which the arch was built, so that they would lay with the grade, that is, so that the water would tend to flow over the edges of the laps rather than against them.

Most of the wet sections of the tunnel were at the ends, where sand-walls had been built for the purpose of providing a smooth surface against which the water-proofing was to be placed; there were several wet places at isolated points in the tunnels, however, and, in order to avoid building sand-walls at these points, the method shown at *E*, Fig. 18, was adopted. This involved a slightly larger excavation, 2 ft. outside of the neat line, up to the height of the top of the bench, where there was not already that much room. The bench-wall was built with a back form on the neat line, the water-proofing was placed as shown, protected by an armor course of brick, and then continued over the arch when this latter was built. The excavation and refilling with rock packing were done at the contractor's expense, which he was willing to assume rather than build these short sections of sand-wall.

The method of water-proofing that part of the timbered section which was very wet, is shown at *F*, Fig. 18, and in Fig. 4, Plate XLVII, and Fig. 1, Plate XLVIII. A lagging of 1-in. boards was nailed up the sides and to the soffit of the segmental timbering, all the spaces outside of this lagging being carefully filled with rock packing. Before starting any concrete work, a single thickness of water-proofing felt was nailed to the inner side of the lagging, which not only served to protect the finished surfaces of the concrete from the

PLATE XLVIII.
PAPERS, AM. SOC. C. E.
FEBRUARY, 1910.
LAVIS ON
BERGEN HILL TUNNELS: PENNSYLVANIA RAILROAD.

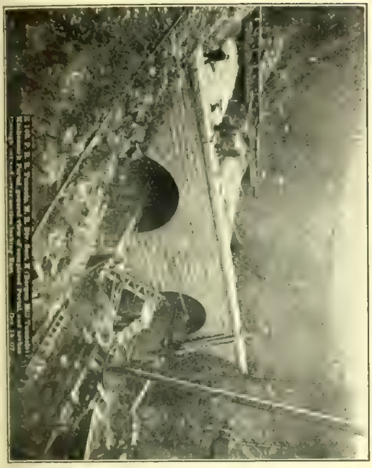


Fig. 1.

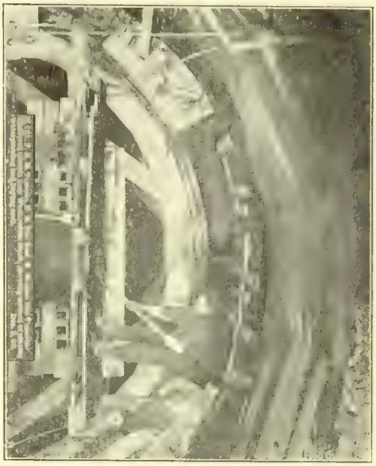


Fig. 3.

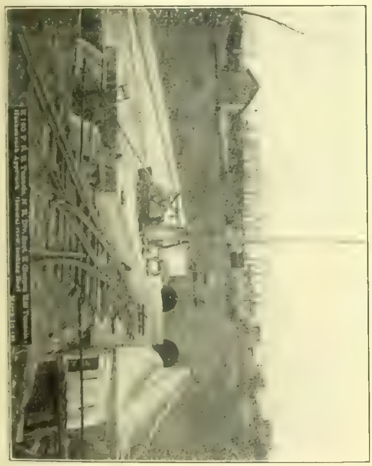


Fig. 2.

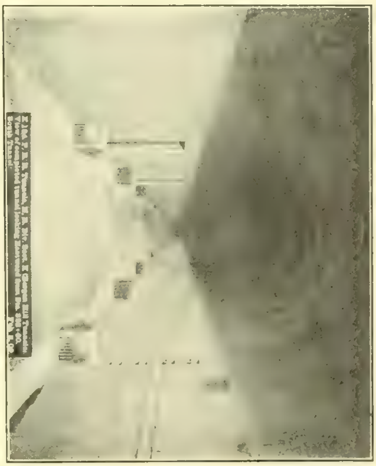


Fig. 4.

water which fell copiously from the roof, but also provided a comparatively dry surface to which the regular six-ply water-proofing could be cemented with pitch and held in position, while the concrete was placed against it.

In placing the water-proofing in this section on the sides, the strips of felt were placed vertically, nailed at the top to the wall-plate, to support their weight, and lapped and cemented with pitch to the sides as on the sand-walls, except that there was no trouble from the overhang. After the bench-wall had been built, the felt was cut just below the nails and about 2 ft. above the top of the bench, so that the mats which were placed over the arch could be inserted behind it. The roof was covered with three-ply mats and lapped over a little more than half, as shown diagrammatically on the drawing.

When the upper part of the arch was reached, where the cementing strength of the pitch was not sufficient to hold the felt in place, the mats were braced temporarily from the centering, as shown by Fig. 1, Plate XLVIII, until the concrete could be packed against it.

Where the water-proofing was placed against the sand-wall, the method of securing the sheets at the top is shown in the small sketch on Fig. 14 and by Figs. 3 and 4, Plate XLV. Fig. 3, Plate XLVI, shows the laps of the sheets and the method of hanging. At the start an attempt was made to stick the water-proofing to the sand-wall, but this could not be done on account of its dampness and the overhang at the top.

The sand-wall water-proofing was kept about 35 ft. ahead of the finished bench-wall, as shown by Fig. 3, Plate XLVI. As the bench-wall form was moved ahead and set, the mat was braced back against the sand-wall from the forms at a point just above the top of the finished bench, care being taken to avoid wrinkles, as, if these were once formed, it was practically impossible to straighten them out.

The completion of the bench-wall left the upper part of this water-proofing stretched taut across the curved top of the sand-wall, forming a chord of the arc. As the arch was built up, the top was gradually slackened so as to allow the concrete to press the mat back into place until the top of the sand-wall was reached, when the end was turned in, as shown at *C*, Fig. 18, or the water-proofing was continued over the arch, if that was necessary.

The desire to obtain a dry tunnel, and the methods adopted to

secure it, were responsible in a great measure for the decision to build the arch in short lengths, as well as the reasons given under the head of arches. Had the tunnels been dry throughout, the method shown at *A*, Fig. 18, could have been used exclusively, and, except for the fact that monolithic concrete might not have been obtained, there would have been no objection to building longer lengths.

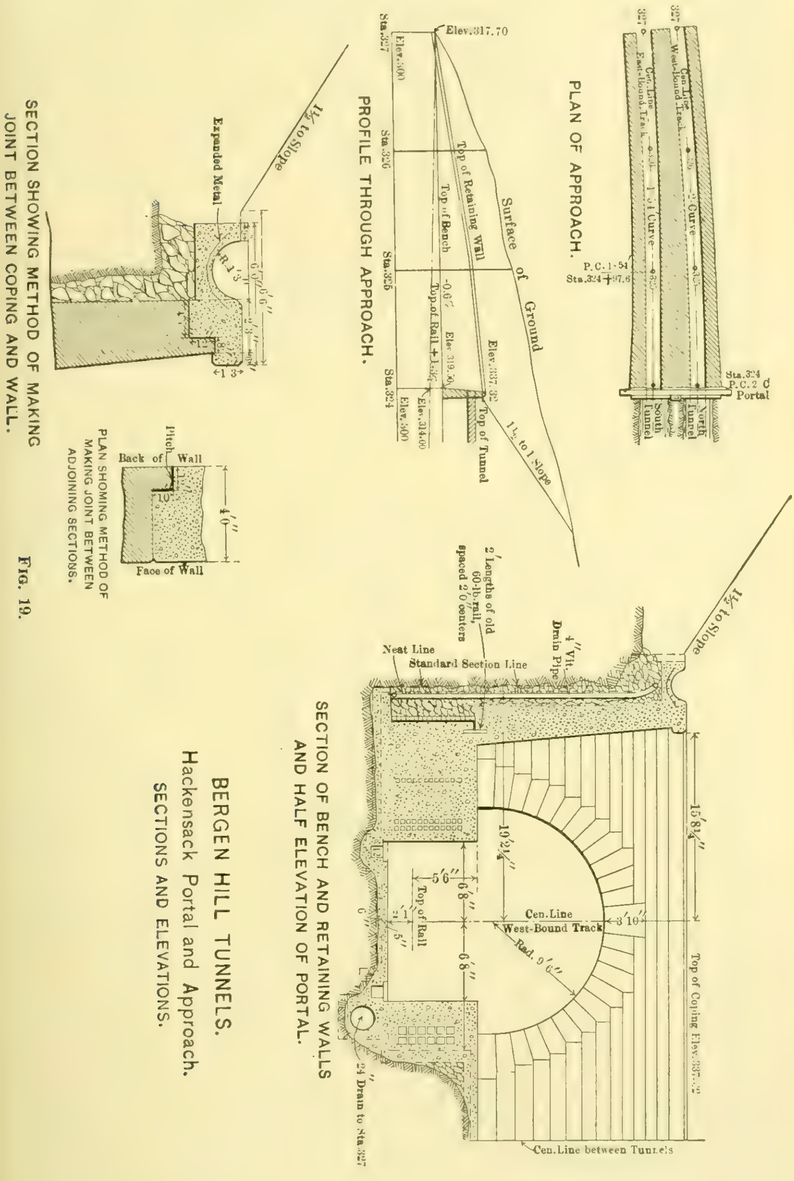
The quantity of water reaching the tunnel drains and flowing out of their lower ends after the completion of the lining was about 100 000 gal. per day, or 75 gal. per min.; of this it is estimated that considerably less than 1% comes through the lining in the form of leaks. The very general distribution of this water over the roof is indicated by the fact that, during the excavation of the first 1 000 ft. of both tunnels from the Weehawken end, oilskins had to be provided for the laborers to induce them to work at all. The success, therefore, of the rock packing as a means of diverting this water to the side drains, is shown, especially in view of the fact that, excluding the cut-and-cover section, only 10% of the length of the arch, 1 189 ft., was water-proofed.

Considerable care was taken to make all joints in the concrete which were in such a position that water might follow through them to the inside of the tunnel lining, in such a manner that they would slope outward toward the rock. The top of the sand-wall is shown by Figs. 14 and 18. The slope of the back of the foundation may be noted in Fig. 18, and the method of making the joint in the arch, in the few instances where a section was not completed at one operation, is shown at *A*, Fig. 18. These joints in the arch were not allowed to be made above a point 60° above the springing line.

Hackensack Portal and Approach.

The approach cut at the western end is 300 ft. long, the alignment being a 2° curve, as shown in Fig. 19. The bench-walls and conduit lines built throughout the length of the tunnels are extended through the approach cut, the top of the former gradually sloping from the portal to the mouth of the cut, where they are just level with the top of the rail, the conduits also being depressed to the same relative position with the tops of the benches.

The top of the rock at the mouth of the cut, Station 327, was from 4 to 6 ft. below the top of the rail, and gradually rose through



BERGEN HILL TUNNELS.
Hackensack Portal and Approach.
SECTIONS AND ELEVATIONS.

FIG. 19.

the approach until at the portal it was about 6 or 8 ft. above the roof of the tunnel. The rock was covered with hardpan. A profile of this part of the work is shown on Fig. 19. The rock throughout the approach was water-bearing to a considerable extent, and a face-wall was built at the sides with free drainage, through rock packing and vitrified and cast-iron drains behind it, to keep this water from flowing over the tops of the bench-walls, and also to keep the lines of conduits dry.

The retaining walls were built in 25-ft. sections, the joints corresponding to those in the benches, being at the even stations, +08, +33, +58, and +83. **V**-shaped joints were made down the face, and the ends of the sections were made as shown by Fig. 19. The back part of the joint was mopped with hot pitch before the next section was built, so that there was practically no bond between any two adjoining sections.

The concrete in these walls was placed late in the season, and the expansion cracks, which were entirely confined to the **V**-shaped joints, were quite small even in the coldest weather of the following winter, nor were there any indications during the past summer of any stresses due to expansion. The coping and drain at the top of the wall were built together, but separate from the rest of the wall, the joint being made as shown in the sketch on Fig. 19. Thus far, there has seemed to be no seepage through either the vertical or horizontal joints.

The portal is built of granite, a half elevation being shown on Fig. 19, the stone being supplied by the Millstone Granite Company, Millstone Point, Conn. Fig. 3, Plate XLVIII, shows the portal and the cut-and-cover section after the arches were completed but not covered.

The forms for the concrete in the approach were made of ordinary dressed lumber, and the surface was rubbed twice after the forms were removed, which was as soon as possible after the concrete had set. The surface was first very lightly rubbed with a piece of soft, light-colored, sandstone to remove any irregularities, being wetted slightly if necessary while being rubbed. After the concrete had become fairly hard and dry, it was rubbed a second time and a uniform texture and color obtained. The completion of this work was delayed until the second week in January, and considerable difficulty was encountered in obtaining a good finish of that part which was built after

cold weather set in, when it was necessary to protect it from frost. Unless extreme care was taken to prevent freezing after the rubbing, the entire surface was likely to scale off, although no cement or other material was added to it after the removal of the forms. A general view of the completed approach is shown by Fig. 4, Plate XLVIII.

TABLE 6.

Title.	Day.			Night.		
	No.	Rate.	Amount.	No.	Rate.	Amount.
Walking bosses	2	$5.00	$10.00			
Timekeeper	2	3.00	6.00			
Watchmen				5	$2.00	$10.00
Waterboys	1	1.50	1.50			
Carpenter foremen	2	3.50	7.00	1	4.00	4.00
Carpenters	14	2.50	35.00	8	2.50	20.00
Pipe-fitters	1	3.00	3.00			
Pipe-fitter's helper	1	1.75	1.75			
Wheelwright	1	2.75	2.75			
Wheelwright's helper	1	1.75	1.75			
Blacksmith	1	3.00	3.00			
Blacksmith's helper	1	1.75	1.75			
Foremen riggers	1	3.00	3.00			
Riggers	6	1.75	10.50			
Foremen trackmen	1	3.00	3.00			
Trackmen	6	1.50	9.00			
Machinist	2	3.00	6.00			
Machinist's helper	1	1.75	1.75			
Electrician	2	3.00	6.00	1	2.50	2.50
Electrician's helper	1	1.75	1.75			
Lampman	1	1.50	1.50			
Pumpman	1	1.50	1.50			
Finishers	3	2.50	7.50			
Hoist engineers	12	3.00	36.00			
Dinky engineers	5	2.75	13.75	1	2.75	2.75
Brakemen	5	1.75	8.75	1	1.75	1.75
Switchmen	1	1.50	1.50			
Barnmen	1	2.00	2.00	1	2.50	2.50
Drivers	9	1.50	13.50			
Foremen ductmen				2	2.50	5.00
Ductmen				5	2.00	10.00
Foremen laborers	13	3.50	45.50	2	3.50	7.00
Laborers	120	1.75	210.00	20	1.75	35.00
Compressor engineer	1	3.50	3.50	1	3.50	3.50
Firemen	2	2.50	5.00	1	2.50	2.50
Oiler	1	1.75	1.75			
Coal passers	2	1.75	3.50	1	1.75	1.75
Totals	324		$469.75	50		$108.25

Total daily labor expense....$578.00

The water finding its way into the side ditches in the approach, which of course included all rain falling in this area, was intercepted just inside the portal and carried back to the mouth of the cut through 24-in. cast-iron pipes laid beneath the conduits in the central bench-wall, thus disposing by natural drainage of a not inconsiderable

quantity of water which would otherwise have flowed through the tunnels to the sump at the Weehawken Shaft, from which it would have had to be pumped to the surface.

About 100 ft. of the tunnel immediately east of the Hackensack Portal was built by the cut-and-cover method, and the arch section used in the tunnel was modified by widening the haunches, the thickness of the arch at the crown being gradually increased from 22 in. at the portal, Station 324, to 34 in. at Station 323, where the regular segmental timbering at the tunnel commenced. A general view of the approach during construction is shown by Fig. 1, Plate XLVI.

Contractor's Organization.

Table 6 shows approximately the number of men employed daily on the tunnel lining, by both the contractor and the sub-contractors, their occupation, the average rate of wages and the total daily expense for labor when the work was in full swing.

Engineering Organization.

The whole of the work of the North River Division was designed and executed under the direction of Charles M. Jacobs, M. Am. Soc. C. E., Chief Engineer, and James Forgie, M. Am. Soc. C. E., Chief Assistant Engineer, the construction of Section "K," Bergen Hill Tunnels, being directly in charge of the writer as Resident Engineer.

PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD COMPANY,
SECTION "K"—BERGEN HILL TUNNELS.

Organization of Staff of Resident Engineer.

Organization Previous to the Holing Through of the Tunnels.

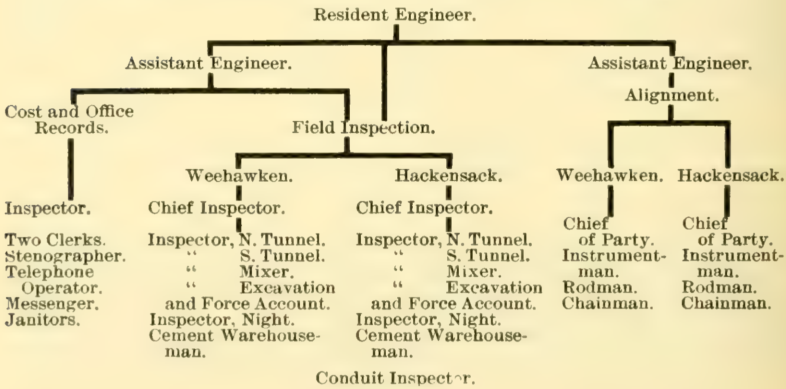


Fig. 29.

ORGANIZATION AFTER THE TUNNELS HAD BEEN HOLED THROUGH.

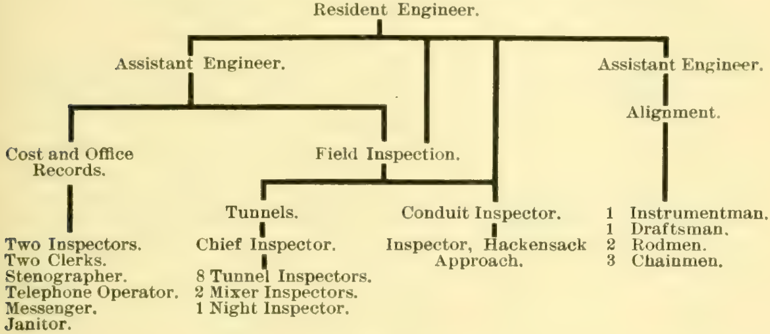


FIG. 21.

The general organization of the staff is shown by the two diagrams, Figs. 20 and 21. Fig. 20 shows the organization previous to the holing through of the tunnels, during which time a separate office was maintained at the western end for the use of the men stationed there; Fig. 21 shows the organization during the latter part of the time, after the tunnels were holed through. The Assistant Engineer in charge of the construction was J. R. Taft, Assoc. M. Am. Soc. C. E.; the Chief Inspector, J. S. Frazer, Jun. Am. Soc. C. E., had charge of about 75% of the work of the lining of the tunnels. The alignment has been from the beginning under the charge of R. L. Reynolds, Assistant Engineer.

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PAPERS AND DISCUSSIONS

EXPANSION OF PIPES.*

By Ralph C. Taggart, Assoc. M. Am. Soc. C. E.

In the arrangement of steam piping (or other piping, the temperature of which is subject to considerable change), proper allowance must be made for expansion. Where the change in temperature, and hence the amount of expansion, is small, the stress may come well within the elastic limit of the metal. In such cases, of course, special arrangements to care for the expansion may not be required.

The calculation to determine the allowable stress in pipe may be readily made. In the case of ordinary iron pipe, we have the following:

The modulus of elasticity of wrought iron, or the stress divided by the strain, equals 29 000 000.

The coefficient of expansion of wrought iron, or the increase in length per degree Fahrenheit per unit length, is 0.00000673.

The stress per degree Fahrenheit, therefore, would be 29 000 000 times 0.00000673, which is equal to 195.2 lb. per sq. in. per degree Fahrenheit difference in temperature. For a change in temperature of 100° Fahr., the stress would become 19 520 lb. per sq. in., which is more than the safe working stress in the iron, especially when it is considered that the stress would be largely increased at the various screw joints, where the thickness of the pipe is reduced by the depth of the thread.

* This paper will not be presented at any meeting, but written communications on the subject are invited for publication with it in *Transactions*.

For ordinary steam apparatus the change in temperature is at least 150° Fahr., so that it becomes impossible for the elasticity of the metal to care for the expansion, even if the piping is very securely tied down. For, when the elastic limit of the metal is reached, a permanent set will result, and if this change in the form of the piping is repeated, a rupture may be expected.

In steam piping, expansion is cared for by two general methods: First, by the use of so-called expansion joints; and second, by the arrangement of the piping, so that the expansion is cared for by the spring of the piping itself.

In apparatus where the straight runs of pipe have not been too long, the second method has been used almost exclusively, although the allowance for expansion has usually been one of judgment or guess-work, and not a matter of calculation.

Where the expansion has been considerable at any one place, it has been common practice for the designing engineer to resort to the use of so-called expansion joints. There are numerous types of these joints, and although many of them have merit, the writer believes that, for many purposes, there are objections to all types. One of the best-known types is made with one metal cylinder sliding or slipping within another. There is, ordinarily, a packed gland or stuffing-box to prevent leakage. An expansion joint of this type should always be anchored, and the pipe which moves within it should also be anchored at a point some distance from it—the distance being determined by the amount of expansion which this particular joint should care for. If the pipe and expansion joint are not thus anchored, the movement of the pipe and the thrust of the steam pressure may carry the inner cylinder of the expansion joint entirely away from the outer cylinder in which it moves. This type requires more or less packing, and although this may not be an important item if only a few expansion joints are used, and if they can be gotten at readily, nevertheless it becomes very important where an engineer has to look after a number of these joints, or where they cannot be reached with the greatest ease.

In a second type of expansion joint, a circular metal disk is fixed at its outer circumference and attached to the expanding pipe near its center. The expansion is taken care of by the spring in the metal disk, and, for this reason, the amount is usually quite small.

A third type of expansion joint is made up of what may be described as a copper pipe with deep corrugations, reinforced with steel rings. Under certain conditions this joint has been very unsatisfactory. Where it has been subjected to varying temperatures, as, for example, in a heating apparatus where the steam pressure is more or less intermittent, the movement in the copper has resulted in breaking at the corrugations. It is claimed, however, that some good results have been obtained where the steam pressure was not very high, and where the pressure and temperature have been very constant.

Some authorities have suggested the use of fittings arranged so that the expansion will be cared for by the twisting of the pipe within the thread of the fitting. This has been done in some cases in low-pressure work, but a little thought or experience will convince one that it is not a method to be relied on, for as soon as the slightest actual twist occurs within the fitting, the pipe becomes loose, and the joint formed by any white lead or varnish is broken. This destroys the effect of the white lead or varnish, and the difficulty of making an ordinary pipe joint tight without some such cement is well known. In many cases, where it is thought that the expansion is cared for by a twisting in a fitting, a careful examination will show that it is really cared for entirely by the spring of the pipe, and it may be set down as a safe rule that, if there is actually a twist in the pipe-thread, due to expansion, there will almost surely be a leak, even where the pressures are low.

It may be interesting, here, to mention what is known as water packing. A so-called steam-tight joint is sometimes made where one piece of metal slips within another, a few circular rings or grooves being cut in one of the cylinders. The fit, of course, must be very good, and the idea is that the condensed steam in the rings or grooves forms a sort of packing. This arrangement is used with engine indicators and with some reducing-pressure valves of the piston type, where a steam-tight joint is desired and where one cylinder must slip within the other. The success of the joint depends on two things: First, and principally, on very accurate workmanship; and second, on the fact that if a very little steam passes through the joint, any part of it which is condensed will evaporate immediately and pass away unnoticed. This is very soon proven, if the discharge from a reducing-pressure valve of this type is closed, and the line leading to it fills with

water, when it will be seen that water is leaking from the joint. This is one reason for the old saying that it is easier to make a joint steam-tight than water-tight.

The most common way in which expansion is cared for in steam piping is by the spring or bending of the pipes, where a change in direction occurs, and, on the whole, this method is the most satisfactory. The allowance to be made for expansion, or the length of the spring pieces, however, is usually guessed at, or is determined by experience, rather than by accurate calculation.

Some years ago, the writer made calculations of the lengths of spring pieces for a large underground installation, and, from these calculations, he made a number of diagrams, which he has used to a considerable extent since that time. More recently, however, the original calculations have been somewhat extended, and this paper contains the resulting diagrams and curves, both new and old, together with a short explanation of their derivation and use. It is believed that they will be of value to designing engineers and others.

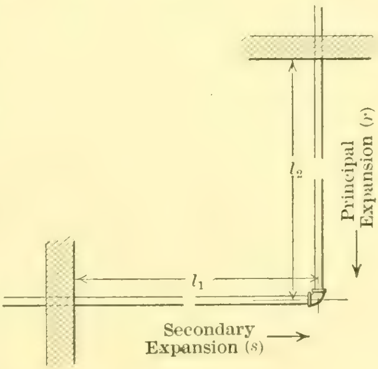

FIG. 1.

Fig. 1 represents two lengths of pipe, l_1 and l_2, connected by a 90° elbow. The lengths, l_1 and l_2, are supposed to represent the distances from the elbow to the points at which the pipe is held in line, or at which the pipe, if horizontal or vertical before expansion, must remain horizontal or vertical after expansion. It will be assumed that the principal expansion acts in a direction at right angles to l_1, and that the secondary or smaller relative expansion, if any, acts at right angles to l_2. Consider, first, a condition in which the secondary expansion is zero. The expansion is then at right angles to l_1, and while the spring in the length of pipe, l_1, must care largely for the expansion, the length, l_2, is also a determining factor. If l_2 becomes zero, or if the pipe at both ends of the length, l_1, is held horizontally, it is easy to determine the length of l_1 required for any given expansion, when the size of the pipe is known.

Under these conditions the formula may be worked out, and will be found to be as follows:

$$l_1^2 = \frac{87\,000\,000\,D\,r}{f} \qquad (1)$$

where the modulus of elasticity is taken as that of wrought iron or steel, *viz.*, 29 000 000.

Where l_1 = the length of pipe under strain, in inches;

r = the expansion, in inches, at right angles to the length of pipe, l_1;

D = the outside diameter of pipe, in inches; and,

f = the maximum fiber stress, in pounds per square inch.

This does not allow for the weakening of the pipe at the fitting.

In the case under consideration, the maximum strain occurs at both ends of the length, l_1, of the pipe, and therefore the lessening in strength at the elbow or fitting should be considered, and allowance made therefor. For example, if the pipe is weaker than the fitting at this point, and if the pipe-threads cut into or reduce the effective section of the pipe to two-thirds of its normal section, the strain calculated should be reduced to two-thirds. The same result is accomplished by calculating for the usual strain, with an increase in expansion to one and one-half, for the reason that the maximum fiber stress varies directly as the expansion.

In this connection it is useful to note the following relations which hold true in the equation, $l_1^2 = \frac{87\,000\,000\,D\,r}{f}$, and also, in general, in other similar equations which will be developed later.

Other quantities remaining constant (f varies directly as r), or for a fixed length and size of pipe, the maximum fiber stress varies directly as the amount of expansion.

Other quantities remaining constant (f varies directly as D), or for a fixed length and expansion of pipe, the maximum fiber stress varies directly as the diameter of the pipe.

Other quantities remaining constant (r varies inversely as D), or for a fixed length and maximum fiber stress, the expansion varies inversely as the outside pipe diameter.

Other quantities remaining constant (f varies inversely as l^2), or for a fixed pipe diameter and expansion, the maximum fiber stress varies inversely as the square of the length.

Other quantities remaining constant (r varies directly as l^2), or for a fixed pipe diameter and maximum fiber stress, the expansion varies directly as the square of the length.

If the length, l_2, is to be considered, as well as the length, l_1, the solution of the problem becomes much more complex, but it can be worked out in a manner similar to the solution of the problem of a continuous girder. The solution is given in the following discussion.

Consider first a pipe with two lengths, l_1 and l_2, at right angles, joined together with an elbow at a. The lengths ac and ad, or l_1 and l_2, are supposed to represent the distances from the elbow to the points at which the pipes pass through walls or are otherwise held at all times in line. Consider now that an expansion occurs in the pipes, with a

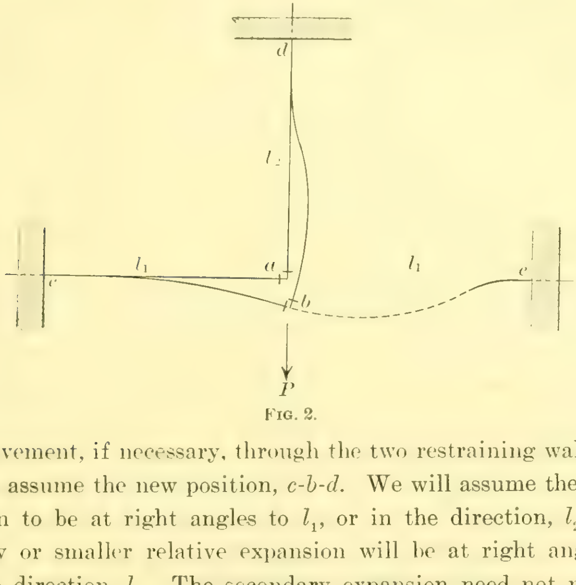

FIG. 2.

slight movement, if necessary, through the two restraining walls, so that the pipes assume the new position, c-b-d. We will assume the principal expansion to be at right angles to l_1, or in the direction, l_2, and the secondary or smaller relative expansion will be at right angles to l_2, or in the direction, l_1. The secondary expansion need not necessarily be less in quantity than the principal expansion, but it is to be less than $\left(\frac{l_2}{l_1}\right)^2$ times the principal expansion. The reason for this will become more apparent as the discussion proceeds, but, of course, it is due to the fact that the expansion largely cared for by l_1 is that at right angles to l_1, and, similarly, the expansion largely cared for by l_2 is that at right angles to l_2, and also because the expansion possible varies as the square of the length of pipe under strain.

Now consider the length, *b-d,* swung through 90°, with the point, *b,* as a center. It will assume the new position, *b-e.* This will change in no way the conditions of stress, if the elbow is considered as a part of the pipe, and it will give an arrangement to which the formula for continuous girders can easily be applied. The walls at *c* and *e* are points of support, and the pipes may be considered as horizontal at these points.

The unknown load, *P,* will act at *b.* The difference in elevation between *c* and *b,* will be called, *r,* and the difference in elevation between *b* and *e,* will be called *s.* The principal expansion is then equal to *r,* and the secondary expansion to *s.* The total horizontal length between *c* and *e* will also be considered as $l_1 + l_2$. It is, in fact, practically $l_1 + l_2 + s$, but since *s* is ordinarily a negligible quantity, as compared with l_1 and l_2, it will be neglected in this connection, although it may be considered in any special case, if desired.

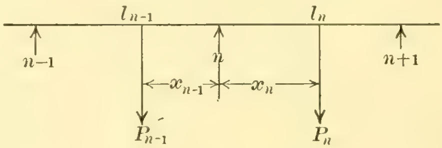

FIG. 3.

The three-moment equation for continuous girders, with not more than one concentrated load on each span, may be written:

$$\frac{M_n}{3}(l_n + l_{n-1}) + M_{n-1}\frac{l_{n-1}}{6} + M_{n+1}\frac{l_n}{6} + \frac{P_n a_n}{6\,l_n}(l_n^2 - a_n^2) + \frac{P_{n-1}a_{n-1}}{6\,l_{n-1}}(l^2_{n-1} - a^2_{n-1})$$
$$= E\,I\left(\frac{Y_{n+1} - Y_n}{l_n} + \frac{Y_{n-1} - Y_n}{l_{n-1}}\right) \ldots\ldots\ldots\ldots\ldots (2)$$

M_{n-1} = moment at support, $n - 1$;
M_n = moment at support, n;
M_{n+1} = moment at support, $n + 1$;
P_{n-1} = concentrated load on span, l_{n-1};
P_n = concentrated load on span, l_n;
l_{n-1} = distance between supports, $n - 1$ and n;
l_n = distance between supports, n and $n + 1$;
X_n = distance from origin to point of application of P_n,
X_{n-1} = distance from origin to point of application of P_{n-1};

$a_n = l_n - X_n$;

$a_{n-1} = l_{n-1} - X_{n-1}$;

E = modulus of elasticity;

I = moment of inertia of section;

Y_{n+1}, Y_n, and Y_{n-1} = ordinates of points of support, $n+1$, n, and $n-1$.

In this case first assume, as in Fig. 4, that n is at c and $n+1$ at e, noting that the origin is at n.

l_{n-1} and l_{n+1} will then equal zero.

Let h equal the difference in elevation between c and e or $(r - s)$.

In all cases the moment at c will be called M_1, and the moment at e, M_2. Then, from Equation 2:

$$\frac{M_1 l_n}{3} + \frac{M_2 l_n}{6} + \frac{P_n a_n}{6 l_n}(l_n^2 - a_n^2) = -E I \frac{h}{l_n} \quad \ldots\ldots\ldots\ldots (3)$$

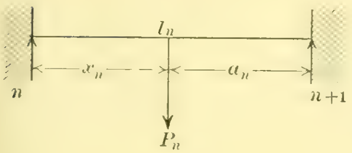

FIG. 4.

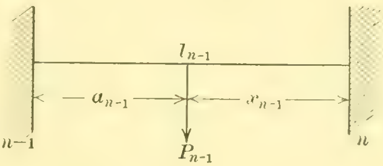

FIG. 5.

If we now assume, as in Fig. 5, that $n - 1$ is at c and n at e, noting again that the origin is at n, we will have, from Equation 2:

$$\frac{M_2 l_{n-1}}{3} + \frac{M_1 l_{n-1}}{6} + \frac{P_{n-1} a_{n-1}}{6 l_{n-1}}(l_{n-1}^2 - a^2_{n-1})$$
$$= E I \frac{h}{l_{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Substituting, in Equation 4, the values used in Equation 3 for l_{n-1}; P_{n-1}; a_{n-1}; *viz.*, l_n; P_n; $l_n - a_n$, we have:

$$\frac{M_2 l_n}{3} + \frac{M_1 l_n}{6} + \frac{P_n a_n}{6 l_n}(2 l_n^2 - 3 a_n l_n + a_n^2) = E I \frac{h}{l_n} \quad \ldots\ldots\ldots (5)$$

If we make L equal to l_n; P equal to P_n; and A equal to a_n, Equations 3 and 5 will then reduce to

$$2 M_1 L + M_2 L + \frac{PA}{L}(L^2 - A^2) = -6 E I \frac{h}{L} \quad \ldots\ldots\ldots (6)$$

$$M_1 L + 2 M_2 L + \frac{PA}{L}(2 L^2 - 3 A L + A^2) = 6 E I \frac{h}{L} \ldots (7)$$

Whence, by multiplying Equation 6 by 2 and subtracting Equation 7:

$$3\, M_1\, L + \frac{2\, P\, A}{L}\, (L^2 - A^2) - \frac{P A}{L}\, (2\, L^2 - 3\, A\, L + A^2) = -18\, E\, I\, \frac{h}{L}$$

or

$$M_1 = -6\, E\, I\, \frac{h}{L^2} - \frac{P\, A^2 (L - A)}{L^2} \ldots\ldots\ldots\ldots\ldots (8)$$

In a similar manner, by multiplying Equation 7 by 2 and subtracting Equation 6:

$$3\, M_2\, L + \frac{2\, P\, A}{L}\, (2\, L^2 - 3\, A\, L + A^2) - \frac{P A}{L}\, (L^2 - A^2) = 18\, E\, I\, \frac{h}{L}$$

or

$$M_2 = 6\, E\, I\, \frac{h}{L^2} - \frac{P A}{L^2}\, (L - A)^2 \ldots\ldots\ldots\ldots\ldots (9)$$

Then Equations 8 and 9 give the moments at the two points of support.

The shear just at the right of the support at *c*, may be expressed as follows:

$$F = \frac{M_2 - M_1 + P\, A}{L} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Substituting the values of M_1 and M_2, as shown in Equations 8 and 9,

$$F = \frac{1}{L} \left(6\, E\, I\, \frac{h}{L^2} - \frac{P\, A}{L^2}\, (L - A)^2 + 6\, E\, I\, \frac{h}{L^2} + \frac{P\, A^2 (L - A)}{L^2} + P\, A\right)$$

or

$$F = 12\, E\, I\, \frac{h}{L^3} + \frac{P\, A^2}{L^3}\, (3\, L - 2\, A) \ldots\ldots\ldots\ldots (11)$$

The three-moment Equation 2 is derived fundamentally from two equations (Figs. 3 and 4), namely,

When $X < X_n;\ M = M_n + F_n\, X \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$

When $X > X_n;\ M = M_n + F_n\, X - P_n\, (X - X_n) \ldots\ldots\ldots (13)$

When M equals the moment at any point, F_n equals the shear at the right of the support, *n*.

Since $\dfrac{d^2\, y}{d\, X^2} = \dfrac{M}{E\, I};\ M = \dfrac{d^2\, y}{d\, X^2}\, E\, I.$

Substituting this value in Equations 12 and 13, integrating and determining constants, we will have:

Where α_1 equals slope distance, X, to right of origin, α_n equals value of α_1, when X equals 0.

For $\quad X < X_n;\ E\,I\,\frac{d\,y}{d\,X} = E\,I\,\tan.\alpha_n + M_n\,X + F_n\,\frac{X^2}{2} \ldots\ldots (14)$

$$X > X_n;\ E\,I\,\frac{d\,y}{d\,X}$$

$$= E\,I\tan.\ \alpha_n + M_n\,X + F_n\,\frac{X^2}{2} - \frac{P_n(X - X_n)^2}{2} \ldots\ldots\ldots (15)$$

Integrating again, and determining constants, we have:

For $X < X_n;\ E\,I\,y = E\,I\,X\,\tan.\ \alpha_n + M_n\,\frac{X^2}{2} + F_n\,\frac{X^3}{6} \ldots\ldots (16)$

$$X > X_n;\ E\,I\,y$$

$$= E\,I\,X\tan.\ \alpha_n + M_n\,\frac{X^2}{2} + F_n\,\frac{X^3}{6} - \frac{P_n\,(X - X_n)^3}{6} \ldots\ldots\ldots (17)$$

If we now give X the value X_n, and Y the value $-\,r$, in either Equations 16 or 17 (*viz.*, substitute the value of X and Y at the point of application of P), we will have:

With $\tan.\ \alpha_n = 0$

$$-\,E\,I\,r = M_n\,\frac{X_n^{\,2}}{2} + F_n\,\frac{X_n^{\,3}}{6} \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

In this equation make M_n equal to the value of M_1 in Equation 8; make F_n equal to the value of F in Equation 11, and substitute for X_n the value $L - A$. We will then have:

$$-\,E\,I\,r = \left(-\,6\,E\,I\,\frac{h}{L^2} - \frac{P\,A^2\,(L - A)}{L^2}\right)\frac{(L - A)^2}{2}$$

$$+ \left[12\,E\,I\frac{h}{L^3} + \frac{P A^2}{L^3}\,(3\,L - 2\,A)\right]\frac{(L - A)^3}{6} \ldots\ldots (19)$$

or simplifying,

$$E\,I\,r = \frac{P\,A^3}{3\,L^3}\,(L - A)^3 + \frac{E\,I\,h}{L^3}\,(L^3 - 3\,A^2\,L + 2\,A^3) \ldots (20)$$

This gives the following value for P:

$$P = \frac{3\,L^3\,E\,I\,r - 3\,E\,I\,h\,(L^3 - 3\,A^2\,L + 2\,A^3)}{A^3\,(L - A)^3} \ldots\ldots\ldots (21)$$

The bending moment will be a maximum at the wall, c, where the bending moment is M_1, therefore,

$$\frac{f\,I}{\frac{1}{2}\,D} = M_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

Substituting the value of M_1 from Equation 8:

$$\frac{f\,I}{\frac{1}{2}\,D} = -6\,E\,I\,\frac{h}{L^2} - \frac{P\,A^2\,(L-A)}{L^2} \qquad (23)$$

From which:

$$P = \frac{-\frac{L^2\,f\,I}{\frac{1}{2}\,D} - 6\,E\,I\,h}{A^2\,(L-A)} \qquad (24)$$

Equating the values of P, as found in Equations 21 and 24, we have:

$$\frac{3\,L^3\,E\,I\,r - 3\,E\,I\,h\,(L^3 - 3\,A^2\,L + 2\,A^3)}{A^3\,(L-A)^3} = \frac{-\frac{L^2\,f\,I}{\frac{1}{2}\,D} - 6\,E\,I\,h}{A^2\,(L-A)} \qquad (25)$$

Simplifying

$$-3\,E\,r = \frac{2\,f\,A}{D\,L}(L-A)^2 - \frac{3\,E\,h}{L^2}(L-A)^2 \qquad (26)$$

or

$$r = -\frac{2\,f\,A\,(L-A)^2}{3\,D\,E\,L} + \frac{h}{L^2}(L-A)^2 \qquad (27)$$

If we make $k\,L = X_n$ and $L - k\,L = A$, then $A = (1-k)\,L$ and, substituting in Equation 27, we have:

$$r = -\frac{2\,f\,(1-k)\,L^2\,k^2}{3\,D\,E} + h\,k^2 \qquad (28)$$

If we substitute the value $(r - s)$ for h, we will have:

$$r = \frac{-2\,f\,(1-k)\,L^2\,k^2}{3\,D\,E} + (r-s)\,k^2 \qquad (29)$$

or

$$r\,(1-k^2) + s\,k^2 = -\frac{2\,f\,(1-k)\,L^2\,k^2}{3\,D\,E} \qquad (30)$$

Or since $L\,k = l_1$

$$r\,(1+k) + s\,\frac{k^2}{1-k} = \frac{-2\,f\,l_1^2}{3\,D\,E} \qquad (31)$$

Where r = principal expansion, in inches;

s = secondary expansion, in inches;

$k = \frac{l_1}{l_1 + l_2}\left(\text{or } \frac{l_1}{L}\right)$;

$L = l_1 + l_2$ (all in inches);

f = maximum fiber stress (pounds per square inch);

D = outside diameter of pipe, in inches; and,

E = modulus of elasticity.

If s equals 0, that is, if the secondary expansion is zero, then:

$$r\,(1 + k) = -\frac{2\,l_1^2 f}{3\,D\,E} \qquad \text{(32)}$$

If $k = 1$; $l_2 = 0$; and $r = -\dfrac{l_1^2 f}{3\,D\,E}$, or

$$l_1^2 = \frac{-3\,D\,E\,r}{f} = \frac{-87\,000\,000\,D\,r}{f} \qquad \text{(33)}$$

which is the same as Equation 1.

This is the condition of a beam, both ends of which are held horizontal while one end is forced to a lower level than the other.

If, on the other hand, s equals zero and k approaches zero (which shows that l_2 becomes very long as compared with l_1), then r approaches a value $-\dfrac{2\,l_1^2 f}{3\,D\,E}$, and would become equal to it in the limit. This is, of course, the condition of a beam fixed at one end and free at the other. In this case the length, l_2, would act as if it (the pipe) were cut off at the elbow. It should be noted that the value of r, when k equals zero, or l_2 equals infinity, is twice that when k equals 1, or l_2 equals zero.

From Equation 31 certain curves have been worked out, which can be used when it is not desired to solve the equation for each independent case. The method of using these curves will be shown for a number of cases.

The curves, Figs. 6 to 22, are calculated (for wrought-iron or steel pipe), for a fixed expansion in a direction at right angles to l_1, which will be called the principal expansion, and, for a zero expansion, in the direction of l_1 or at right angles to l_2, which will be called the secondary expansion. If the secondary expansion must be considered, it may be calculated from the equations which have been derived, or one may make use of the curves, Figs. 23 and 24, which are to be used in connection with the curves, Figs. 6 to 22, as will be explained later. It will be noted that the lengths of pipe, l_1 and l_2, are given in feet in all the diagrams, although, in the equations, the units are in inches.

Consider first the expansion in a 4-in. pipe, where the principal expansion is 6 in., and where the secondary expansion (or that at right angles to the principal expansion), is negligible. This length can be determined directly from Fig. 13. If l_2 is zero, the length of l_1 will be 37 ft. If l_2 equals 10 ft., it will be more than $\dfrac{l_1}{4}$, because l_1 must

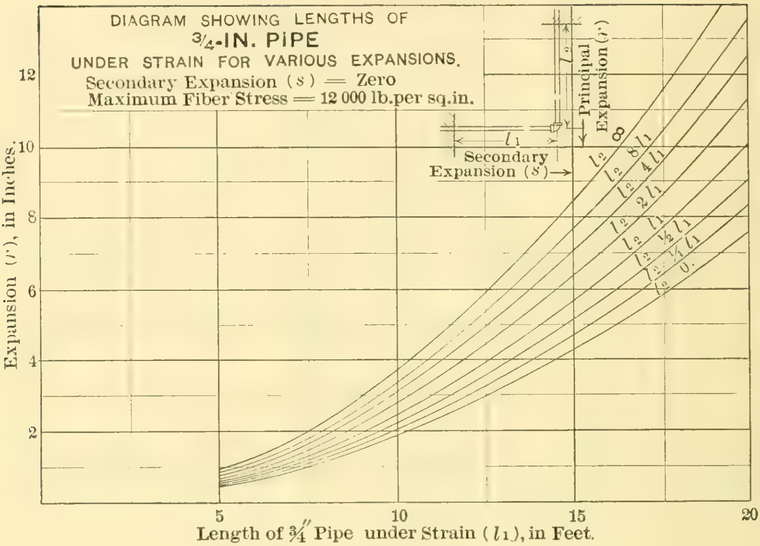
DIAGRAM SHOWING LENGTHS OF
3/4-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Principal Expansion (r)
Secondary Expansion (s)
Expansion (r), in Inches.
Length of 3/4" Pipe under Strain (l1), in Feet.

Fig. 6.

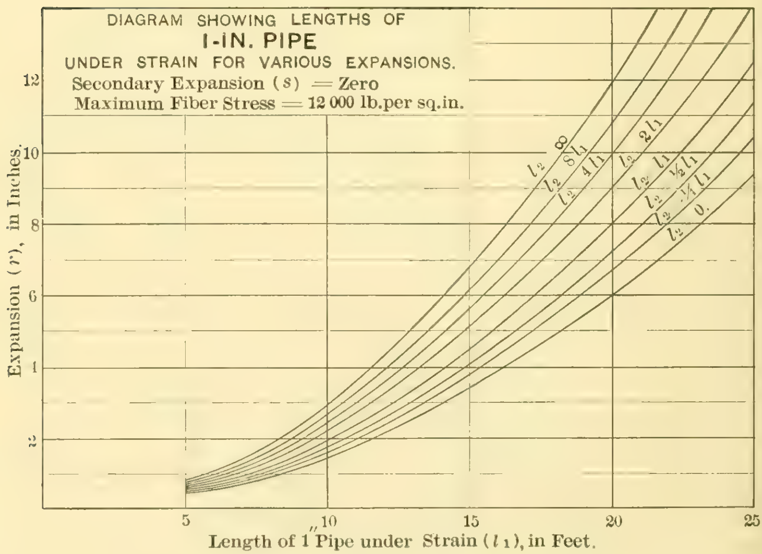
DIAGRAM SHOWING LENGTHS OF
1-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 1" Pipe under Strain (l1), in Feet.

Fig. 7.

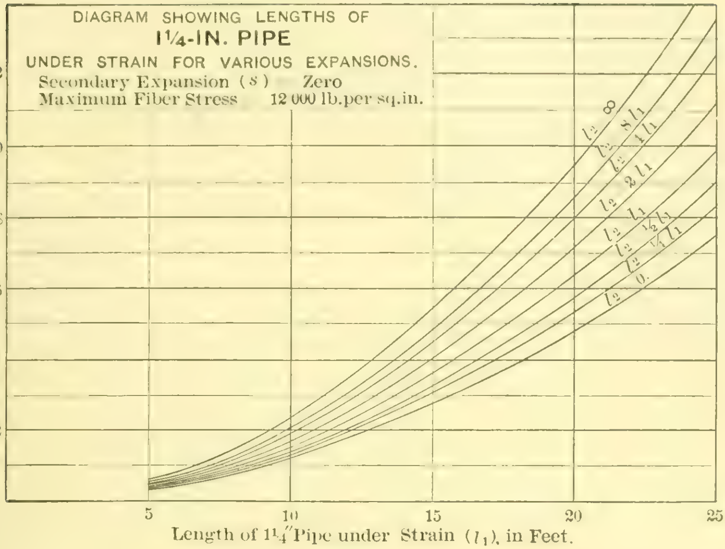
DIAGRAM SHOWING LENGTHS OF
1¼-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 1¼″ Pipe under Strain (l_1), in Feet.
2
4
6
8
10
12
5
10
15
20
25
l_2 ∞
l_2 $8 l_1$
l_2 $4 l_1$
l_2 $2 l_1$
l_2 l_1
l_2 $½ l_1$
l_2 $¼ l_1$
l_2 0.

FIG. 8.

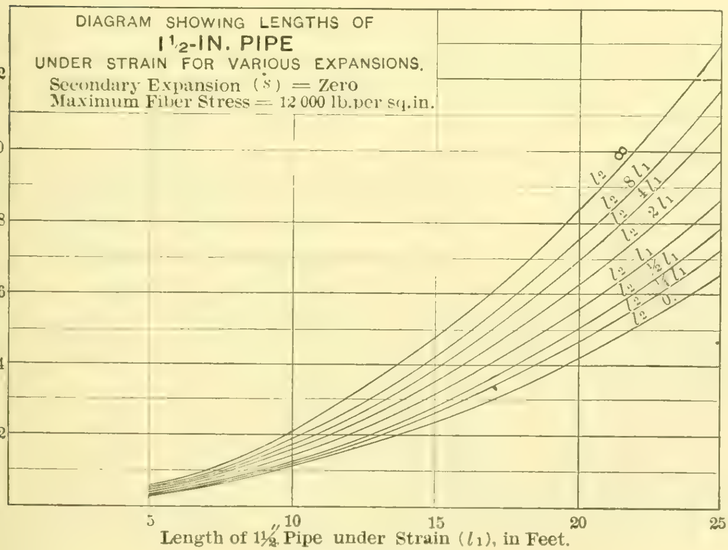
DIAGRAM SHOWING LENGTHS OF
1½-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 1½″ Pipe under Strain (l_1), in Feet.
2
4
6
8
10
12
5
10
15
20
25
l_2 ∞
l_2 $8 l_1$
l_2 $4 l_1$
l_2 $2 l_1$
l_2 l_1
l_2 $½ l_1$
l_2 $¼ l_1$
l_2 0.

FIG. 9.

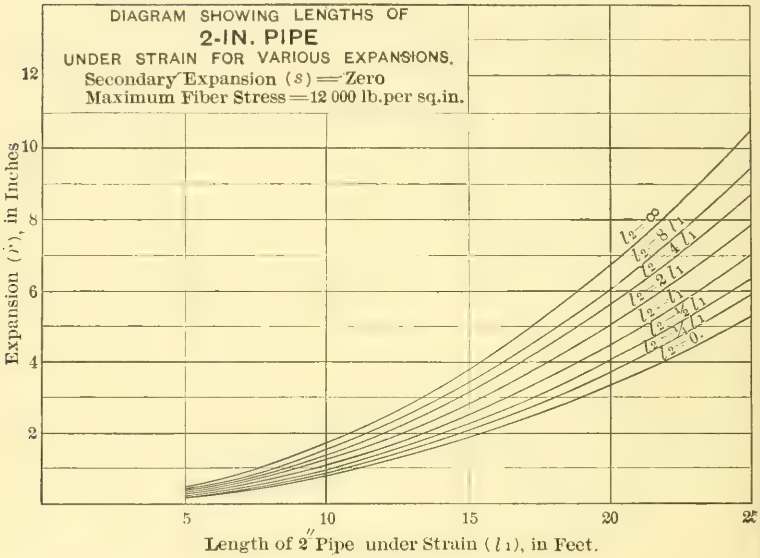
DIAGRAM SHOWING LENGTHS OF
2-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches
Length of 2" Pipe under Strain (l_1), in Feet.
$l_2 = \infty$
$l_2 = 8 l_1$
$l_2 = 4 l_1$
$l_2 = 2 l_1$
$l_2 = l_1$
$l_2 = \frac{1}{2} l_1$
$l_2 = \frac{1}{4} l_1$
$l_2 = 0.$

Fig. 10.

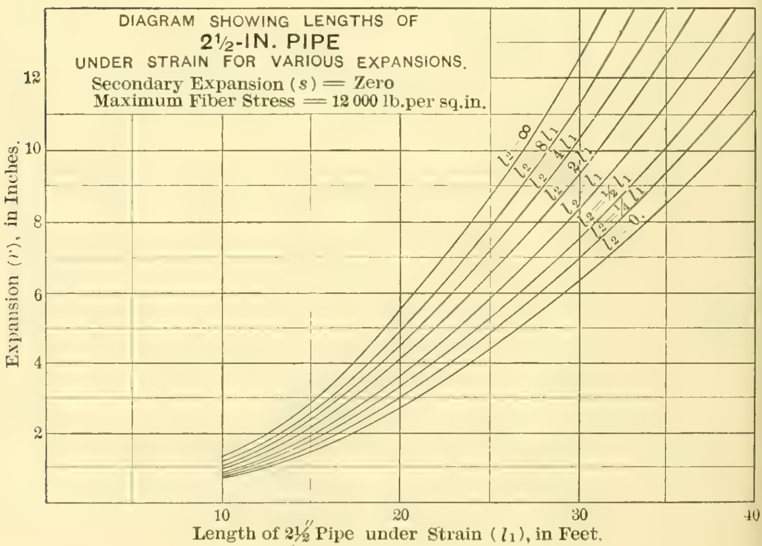
DIAGRAM SHOWING LENGTHS OF
2½-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 2½" Pipe under Strain (l_1), in Feet.
$l_2 = \infty$
$l_2 = 8 l_1$
$l_2 = 4 l_1$
$l_2 = 2 l_1$
$l_2 = l_1$
$l_2 = \frac{1}{2} l_1$
$l_2 = \frac{1}{4} l_1$
$l_2 = 0.$

Fig. 11.

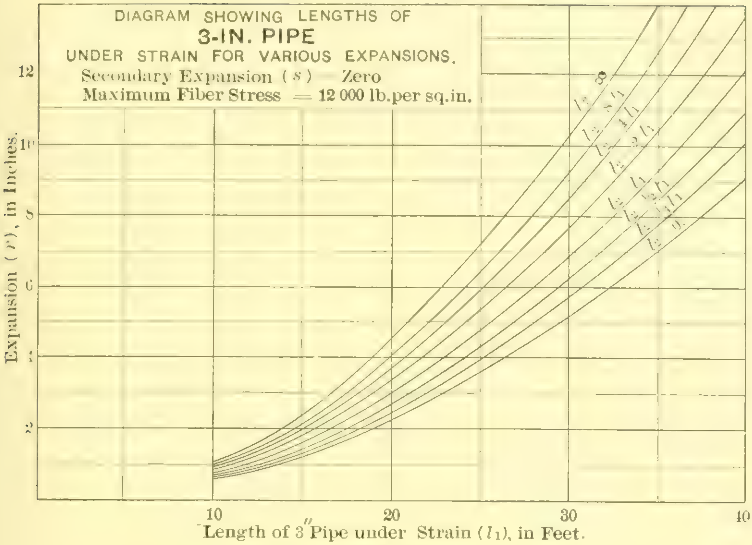
DIAGRAM SHOWING LENGTHS OF
3-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 3" Pipe under Strain (l_1), in Feet.

FIG. 12.

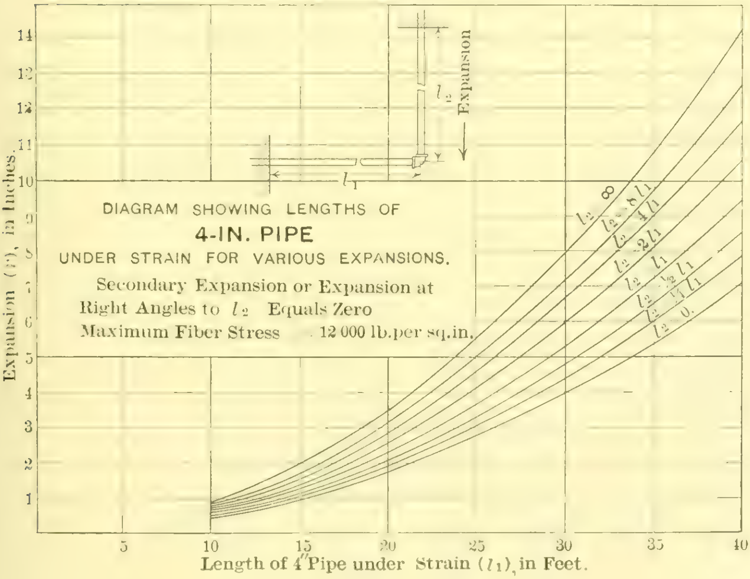
DIAGRAM SHOWING LENGTHS OF
4-IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion or Expansion at
Right Angles to l_2 Equals Zero
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion
Expansion (r), in Inches.
Length of 4" Pipe under Strain (l_1), in Feet.

FIG. 13.

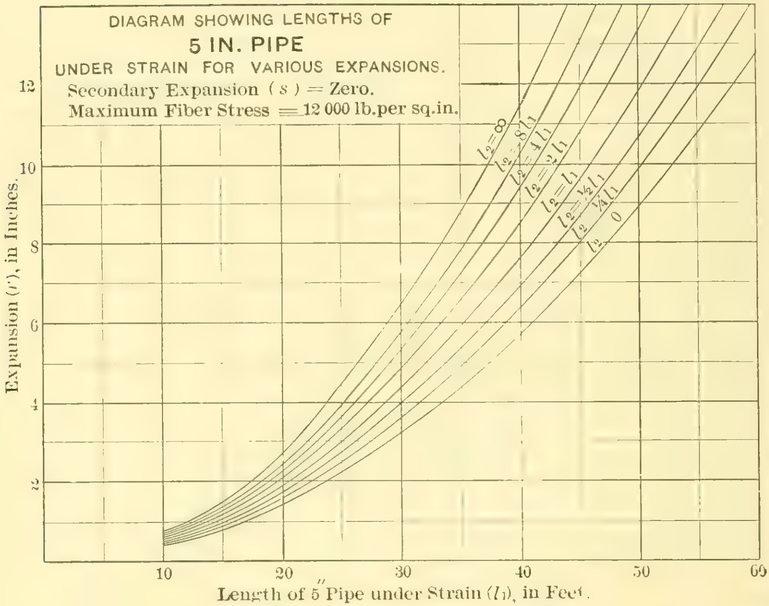
DIAGRAM SHOWING LENGTHS OF
5 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero.
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 5" Pipe under Strain (l1), in Feet.

Fig. 14.

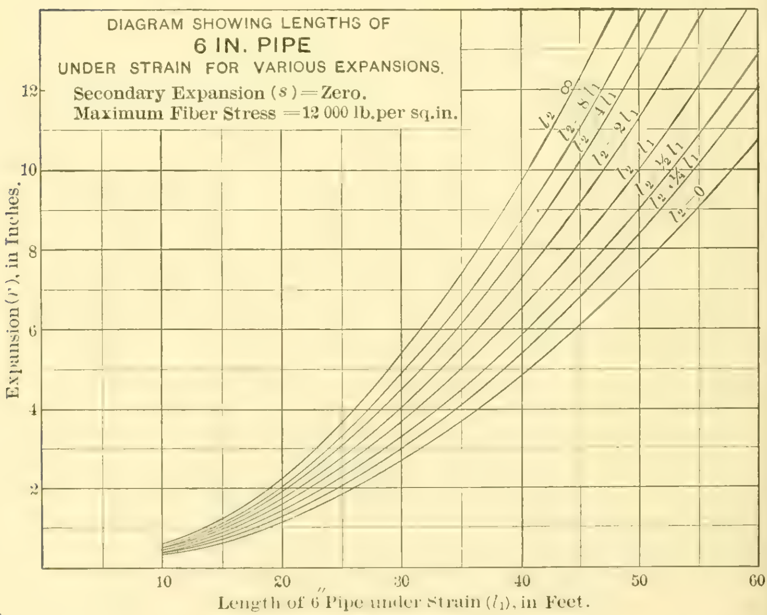
DIAGRAM SHOWING LENGTHS OF
6 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero.
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 6" Pipe under Strain (l1), in Feet.

Fig. 15.

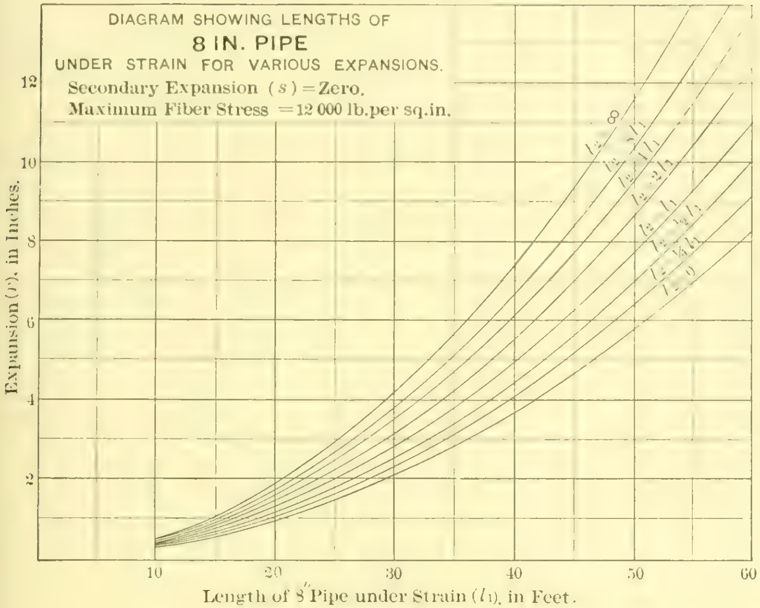
DIAGRAM SHOWING LENGTHS OF
8 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero.
Maximum Fiber Stress = 12 000 lb.per sq.in.
Expansion (r), in Inches.
Length of 8" Pipe under Strain (l_1), in Feet.

FIG. 16.

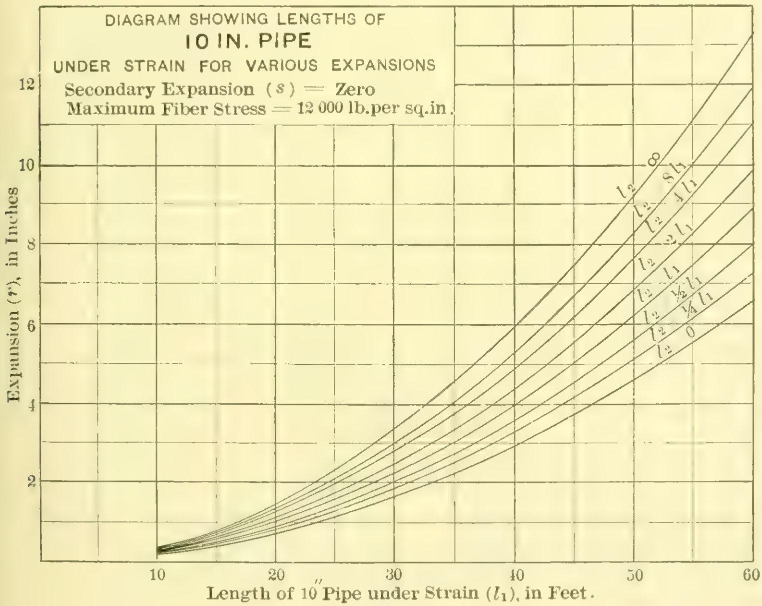
DIAGRAM SHOWING LENGTHS OF
10 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS
Secondary Expansion (s) = Zero
Maximum Fiber Stress = 12 000 lb.per sq.in.
Expansion (r), in Inches
Length of 10" Pipe under Strain (l_1), in Feet.

FIG. 17.

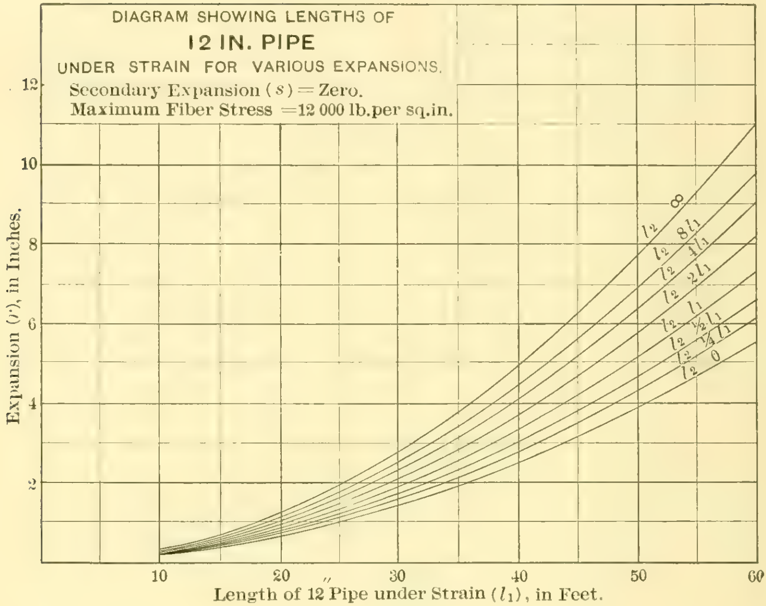
DIAGRAM SHOWING LENGTHS OF
12 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero.
Maximum Fiber Stress =12 000 lb.per sq.in.
Expansion (r), in Inches.
Length of 12 Pipe under Strain (l_1), in Feet.

FIG. 18.

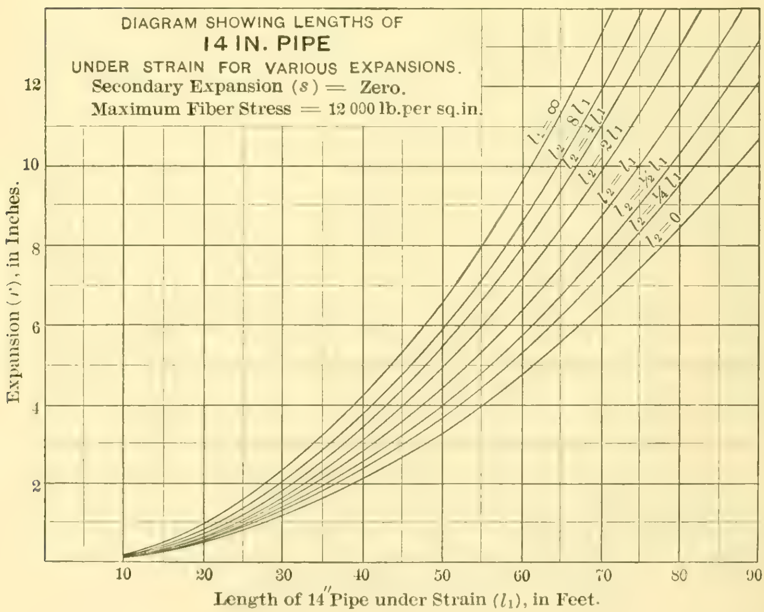
DIAGRAM SHOWING LENGTHS OF
14 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero.
Maximum Fiber Stress = 12 000 lb.per sq.in.
Expansion (r), in Inches.
Length of 14" Pipe under Strain (l_1), in Feet.

FIG. 19.

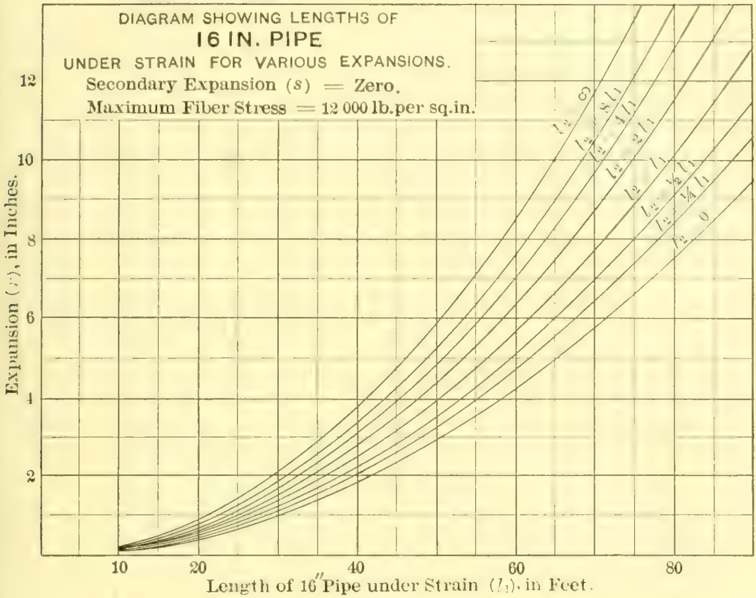
DIAGRAM SHOWING LENGTHS OF
16 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS.
Secondary Expansion (s) = Zero.
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 16" Pipe under Strain (l_1), in Feet.
2
4
6
8
10
12
10
20
40
60
80

FIG. 20.

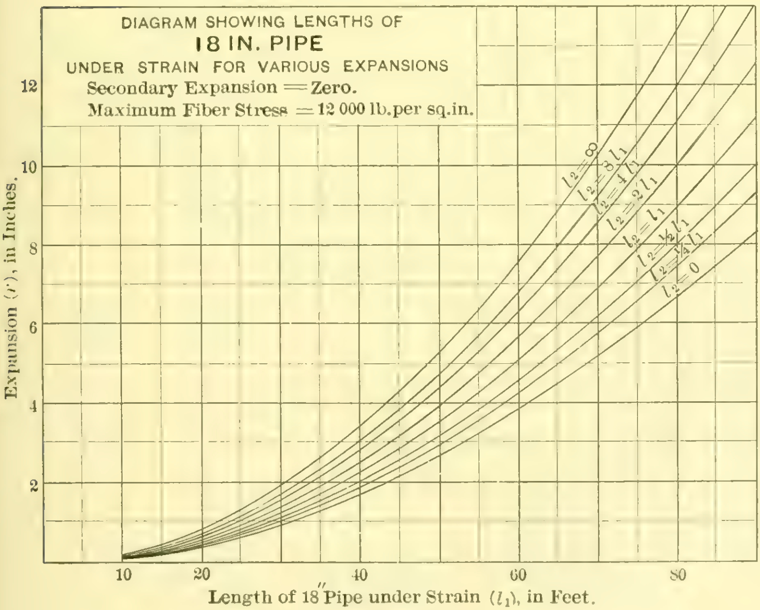
DIAGRAM SHOWING LENGTHS OF
18 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS
Secondary Expansion = Zero.
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 18" Pipe under Strain (l_1), in Feet.
$l_2 = \infty$
$l_2 = 8 l_1$
$l_2 = 4 l_1$
$l_2 = 2 l_1$
$l_2 = l_1$
$l_2 = \frac{1}{2} l_1$
$l_2 = \frac{1}{4} l_1$
$l_2 = 0$
2
4
6
8
10
12
10
20
40
60
80

FIG. 21.

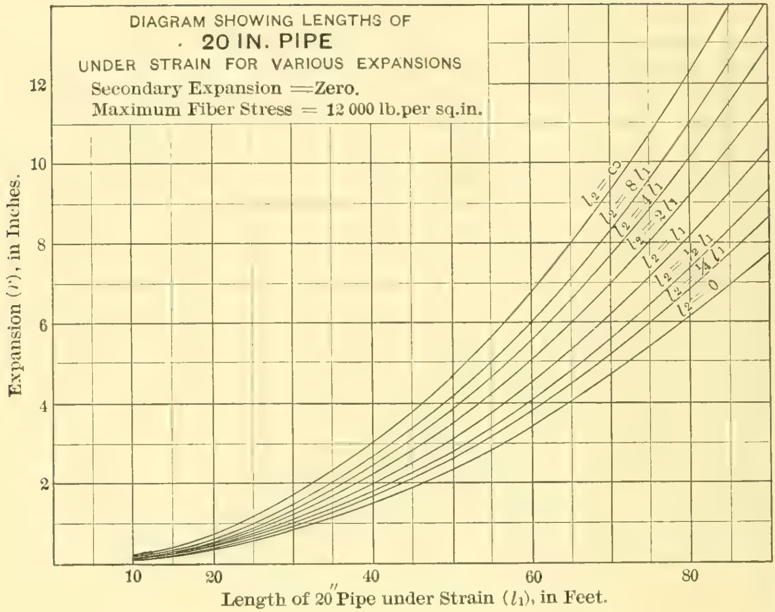
DIAGRAM SHOWING LENGTHS OF
20 IN. PIPE
UNDER STRAIN FOR VARIOUS EXPANSIONS
Secondary Expansion = Zero.
Maximum Fiber Stress = 12 000 lb. per sq. in.
Expansion (r), in Inches.
Length of 20" Pipe under Strain (l_1), in Feet.
$l_2 = \infty$
$l_2 = 8 l_1$
$l_2 = 4 l_1$
$l_2 = 2 l_1$
$l_2 = l_1$
$l_2 = \frac{1}{2} l_1$
$l_2 = \frac{1}{4} l_1$
$l_2 = 0$

FIG. 22.

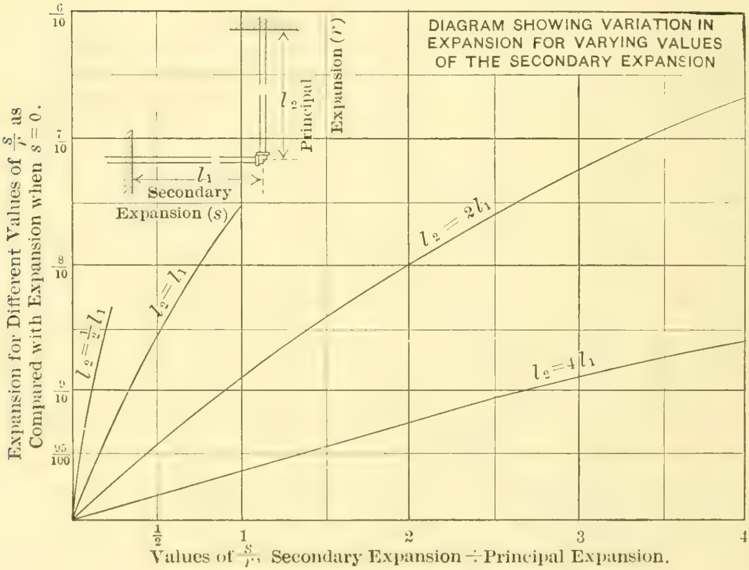
DIAGRAM SHOWING VARIATION IN
EXPANSION FOR VARYING VALUES
OF THE SECONDARY EXPANSION
Expansion for Different Values of $\frac{s}{r}$ as Compared with Expansion when $s = 0$.
Values of $\frac{s}{r}$, Secondary Expansion ÷ Principal Expansion.
Principal Expansion (r)
Secondary Expansion (s)
l_1
l_2
$l_2 = \frac{1}{2} l_1$
$l_2 = l_1$
$l_2 = 2 l_1$
$l_2 = 4 l_1$

FIG. 23.

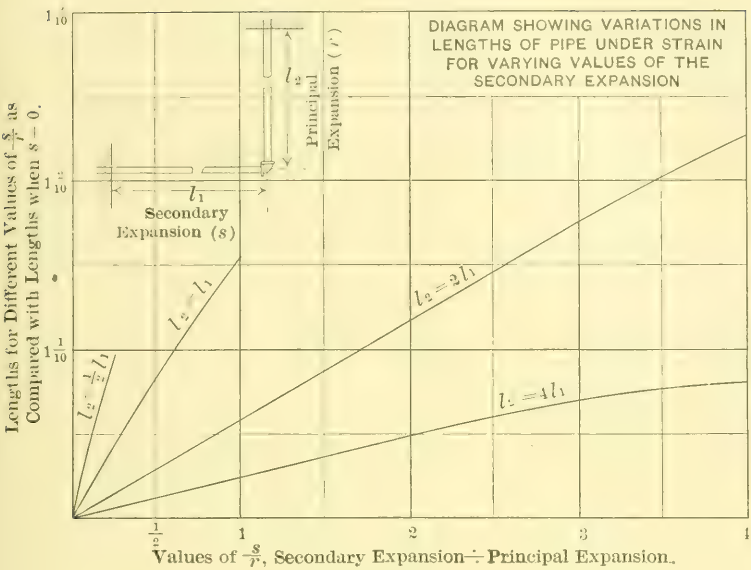
DIAGRAM SHOWING VARIATIONS IN LENGTHS OF PIPE UNDER STRAIN FOR VARYING VALUES OF THE SECONDARY EXPANSION
Lengths for Different Values of $\frac{s}{r}$ as Compared with Lengths when $s = 0$.
Principal Expansion (r)
Secondary Expansion (s)
l_1
l_2
$l_2 = \frac{1}{2} l_1$
$l_2 = l_1$
$l_2 = 2 l_1$
$l_2 = 4 l_1$
$1\frac{1}{10}$
$\frac{1}{2}$
1
2
3
4
Values of $\frac{s}{r}$, Secondary Expansion ÷ Principal Expansion.

FIG. 24.

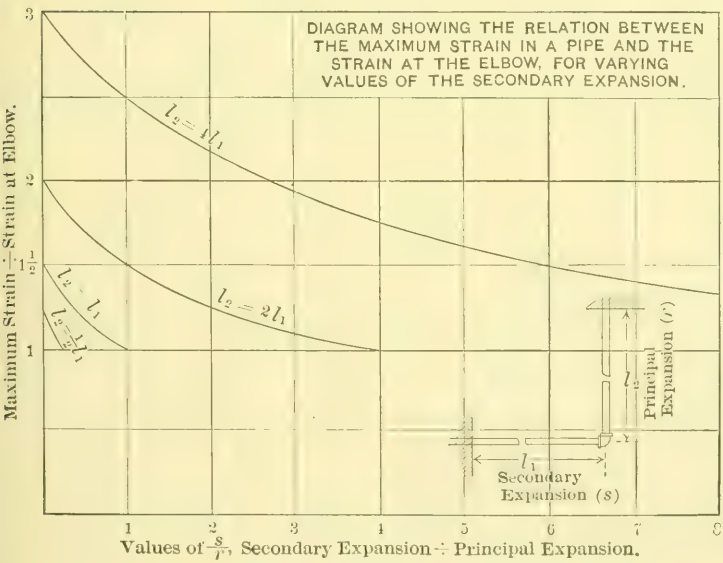
DIAGRAM SHOWING THE RELATION BETWEEN THE MAXIMUM STRAIN IN A PIPE AND THE STRAIN AT THE ELBOW, FOR VARYING VALUES OF THE SECONDARY EXPANSION.
Maximum Strain ÷ Strain at Elbow.
3
2
$1\frac{1}{2}$
1
$l_2 = 4 l_1$
$l_2 = 2 l_1$
$l_2 = l_1$
$l_2 = \frac{1}{2} l_1$
Principal Expansion (r)
Secondary Expansion (s)
l_1
l_2
1
2
3
4
5
6
7
8
Values of $\frac{s}{r}$, Secondary Expansion ÷ Principal Expansion.

FIG. 25.

equal something less than 37 ft., if l_2 has any value at all. With l_2 equal to 10 ft., l_2 is more than $\frac{l_1}{4}$ and undoubtedly less than $\frac{l_1}{2}$. If l_2 equals $\frac{l_1}{2}$, it will be seen from Fig. 13, that l_1 will be a little less than 34 ft., and if l_2 equals $\frac{l_1}{4}$, l_1 equals 35 ft. It will be seen, therefore, that l_2 is about two-sevenths of l_1 or nearly $\frac{l_1}{4}$, and that l_1 should be taken as 34½ or 35 ft.

If the length l_2 becomes equal to 8 l_1, it will be seen from Fig. 13 that l_1 should equal 27½ ft. When l_2 becomes very long, the fact as to whether it can move freely must, of course, be taken into consideration. If it must slip over fixed supports, the friction of slippage will, of course, have the same effect as the shortening of the length, l_2. On the other hand, it often happens that pipes passing through walls, or in similar conditions, will be held so as to permit of some slight side movement, although it may not be allowed for in the calculations. This, of course, would have the same effect as an increase in the length of pipe under strain.

Let us now consider the expansion in a 4-in. pipe where the principal expansion is 6 in., the secondary expansion is 3 in., and the lengths of l_1 and l_2 are to be equal. From Fig. 24, it will be seen, when the principal expansion divided by the lesser or secondary expansion $\left(\text{or } \frac{s}{r}\right) = \frac{1}{2}$, and when $l_1 = l_2$, that (compared with the case where the secondary expansion equals zero) the lengths should be increased in the ratio of 1 to 1.085, or, from Fig. 23, it will be seen that the expansion should be decreased in the ratio of 1 to 0.85.

From Fig. 13 it will be seen that l_1 should be nearly 32 ft. for a 4-in. pipe with a 6-in. expansion (the secondary expansion being zero and $l_1 = l_2$). If, in addition to the principal expansion of 6 in., there is a secondary expansion of 3 in., the lengths should be increased, as before stated, in the ratio of 1 to 1.085, or 32 ft. should be changed to nearly 35 ft. If, however, it is desired not to increase these lengths, the lessened amount of expansion or the increased maximum fiber stress can be determined. From Fig. 23 it has been determined that the expansion should be decreased in the ratio of 1 to 0.85, or

6 and 3 in. should become 5.1 and 2.55 in., respectively. If, however, it is desired to maintain the 6- and 3-in. expansion, it will be seen from the equations that the fiber stress varies directly as the expansion, and hence the maximum fiber stress will become

$$12\,000 \times \frac{1}{0.85} = 14\,118 \text{ per sq. in.}$$

There is one factor which has already been mentioned, to which, however, further attention should be given, that is the question as to how much allowance should be made for the weakening of a pipe at a fitting due either to the strength of the fitting or the threads on the pipe. In order to determine what this allowance should be, we must make $\frac{f\,I}{\frac{1}{2}\,D}$, in Equation 22, equal to the moment where $X = k\,L$, instead of to M_1, where $X = 0$. Following through similar succeeding equations, we will secure the equation:

$$-r = \frac{f}{3\,E\,D}\,L^2\,k\,(k - 1) - h\,k \quad \ldots\ldots\ldots\ldots (34)$$

or

$$r + s\,\frac{k}{1 - k} = \frac{f\,l_1^2}{3\,E\,D\,k} \quad \ldots\ldots\ldots\ldots (35)$$

The comparative values of the pipe strain at the joint and the fixed point of the pipe, have been determined from Equation 35, and are shown graphically in Fig. 25.

In using this diagram in the following discussion, the loss in strength at the elbow is calculated as one-third. Therefore, an allowance should be made for the weakening at the fitting when the maximum strain is less than $\frac{1}{1 - \frac{1}{3}}$, or $1\frac{1}{2}$ times the strain at the elbow. An examination of the curves on Fig. 25 will show that this is practically always the case when $l_2 = l_1$, or anything less than l_1. It is also the case when $l_2 = 2\,l_1$, and the secondary is equal to or larger than the principal expansion. It will be remembered that the principal expansion is always larger than $\left(\frac{l_2}{l_1}\right)^2$ times the secondary expansion, where l_1 is the length of pipe under strain at right angles to the direction of the principal expansion, and l_2 is the length of pipe under strain at right angles to the secondary expansion, but the principal expansion is not necessarily larger in quantity than the secondary expansion.

The allowance will depend on the ratio of the maximum strain to the strain at the elbow, which values are shown by the curves in Fig. 25. When $l_2 = 0$, the strain at the elbow equals the strain at the point where the pipe is held in line, and the strain at all intermediate points is also the same. The allowance for the weakening at the elbow, or for any joint between the elbow and the point where the pipe is held in line, therefore, should be in the ratio of 1 to $1\frac{1}{2}$ or the strain allowable should be two-thirds of what otherwise might be calculated when $l_2 = 0$.

If l_2 has some other value, for example, if $l_2 = 2\,l_1$, and if $\frac{s}{r} = 2$, it will be seen, from Fig. 25, that the maximum strain is $1\frac{1}{4}$ times the strain at the elbow. If we calculate the elbow to be only two-thirds as strong as the pipe, the strain in the latter should be reduced to $\frac{2}{3} \times 1\frac{1}{4}\left(=\frac{5}{6}\right)$ of what the pipe might stand, so as not to overstrain the material at the elbow. If there is a fitting half way between the elbow and the point at which the pipe is held in line, the maximum strain would be greater than the strain at this point, in the ratio of 1 to a quantity half way between 1 and $1\frac{1}{4}$, or in the ratio of 1 to $1\frac{1}{8}$.

If the fitting were farther from the elbow, its distance being two-thirds of the total distance between the point at which the pipe is held in line and the elbow, the ratio would be 1 to $\left(1 + \frac{1}{3}\right)\frac{1}{4}$, which is equal to the ratio of 1 to $1\frac{1}{12}$.

When $l_2 = 0$, therefore, the allowance for the weakening at the elbow should be made as follows:

$$\frac{\text{The new } l_1^2 \text{ and } l_2^2}{\text{The old } l_1^2 \text{ and } l_2^2} = \frac{1}{\frac{2}{3}}, \text{ or,}$$

$$\frac{\text{The new } l_1 \text{ and } l_2}{\text{The old } l_1 \text{ and } l_2} = \sqrt{\frac{3}{2}} = \sqrt{1.5} = 1.225,$$

or the new lengths should equal 1.225 times the old lengths.

An examination of the equation and curves will also show that this same rule may be followed closely when the secondary expansion, although not zero, is still small as compared with $\left(\frac{l_2}{l_1}\right)^2$ times the principal expansion, and, in no case, will the allowance be greater than this amount.

The diagrams may be used for a variety of combinations, and their adaptability is well illustrated by Fig. 26.

An arrangement of piping is assumed, in which a tee connects an 8- and a 6-in. pipe on the run and a 4-in. pipe branches from the tee at right angles to both. The length of the 8-in. pipe from the tee to the point at which it is held in line will be assumed to be 30 ft., and that of the 6-in. pipe will be assumed to be 25 ft. If the movement of the tee in the direction of the 6- and 8-in. pipes is 2 in., what should the length of the 4-in. pipe be from the tee to the point at which it is held in line?

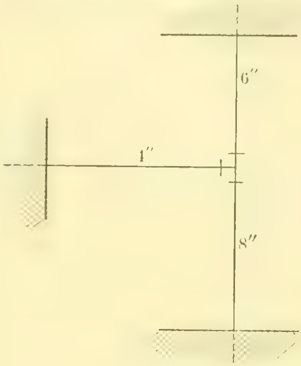

FIG. 26.

It will first be assumed that the expansion of the tee in the direction of the 4-in. pipe is a negligible quantity. From the formula it is seen that the bending for a fixed maximum fiber stress varies inversely as the diameter of the pipe and the square of the length of pipe. The 30 ft. of 8-in. pipe, therefore, could, for a fixed maximum fiber stress, be bent only one-half as much as 30 ft. of 4-in. pipe. Therefore, the 30 ft. of 8-in. pipe is equivalent in its power to bend to 21.2 ft. of 4-in. pipe, since the lengths vary as the square root of the bending power, and $\frac{21.2}{30} = \sqrt{\frac{1}{2}}$. In the same way, the 25 ft. of 6-in. pipe is equivalent to $\frac{25}{\sqrt{1.5}} = \frac{25}{1.224} = 20$ ft. (about).

We have now the double stiffness of an equivalent of 21.2 ft. of 4-in. pipe and 20 ft. of 4-in. pipe. The stiffness is proportional to $\frac{1}{l^2}$, or to the reciprocal of the length squared. Therefore, the combined stiffness of the two 6- and 8-in. pipes would be equivalent to $\frac{1}{(21.2)^2} + \frac{1}{20^2} = \frac{849.44}{179\,776}$, which would be equivalent to a 4-in. pipe, with a length of $\sqrt{\frac{179\,776}{849.44}} = \sqrt{211.64} = 14.54$ ft.

If we use 14.54 as l_2, therefore, in Fig. 13, we can secure the necessary length of 4-in. pipe.

We see from this diagram that, if $l_2 = 0$, 2 in. of expansion for a 4-in. pipe would require a length of $21\frac{1}{4}$ ft. of 4-in. pipe. If $l_2 = l_1$, l_1 would be $18\frac{1}{8}$ ft., but l_2 is equivalent to 14.5 ft. The next smaller value for l_2 is l_2 equals $\frac{1}{2}\,l_1$. In this case, l_1 would equal $19\frac{3}{8}$ ft. In the first case, if $l_2 = l_1$, l_2 would be $18\frac{1}{8}$. In the second case, if $l_2 = \frac{1}{2}\,l_1$, l_2 would be $9\frac{11}{16}$ ft., but l_2 is actually $14\frac{1}{2}$ ft., or about half-way between the two; therefore, l_1 lies between $19\frac{3}{8}$ and $18\frac{1}{8}$, and would not be far from 19 ft.

If now there should be a secondary expansion of $\frac{1}{2}$ in., it would be necessary to increase the value of l_1. If l_2 could not be increased proportionately, the value of $\frac{l_2}{l_1}$ would be decreased, and instead of being $\frac{14\frac{1}{2}}{19}$, or approximately $\frac{3}{4}$, it would become something less. From Fig. 24 it will be seen that when the secondary expansion divided by the principal expansion, or $\frac{s}{r} = \frac{1}{4}$, and when $l_2 = \frac{1}{2}\,l_1$, that the new length should be about 1.1 of the old length. This, however, would change l_1 so little that the value of $\frac{l_2}{l_1}$, while less than $\frac{3}{4}$, would not be nearly so small as $\frac{1}{2}$. We can, therefore, approximate the value of $\frac{l_2}{l_1}$ as $\frac{9}{10} \times \frac{3}{4} = \frac{27}{40} = 0.675$, or about $\frac{2}{3}$, and we can approximate the required length of l_1 from Fig. 24, as about 1.09 of the old length of 19 ft. or the new length of l_1 would become about $19 \times 1.09 = 20.71$, or about $20\frac{3}{4}$ ft.

Let us now consider a case in which the strain is not caused by an expansion or movement at the tee, and in which the end of the 4-in. pipe farthest from the tee is not held in line. The problem will be to find what bending is possible at the end of the 4-in. pipe farthest from the tee, if this end is not held horizontal or in its original direction. The length of the 8- and 6-in. pipes will be the same as before, and the length of the 4-in. pipe will be the same as in the last case, *viz.,* $20\frac{3}{4}$ ft.

In this case the 8- and 6-in. pipes together have an equivalent length of 14.54 ft. of 4-in. pipe.

It is apparent that, in this case, the bending will be the same as for a 4-in. pipe of length $(20.7 + 14.54) = 35.24$ ft. with its end free. A free end is a similar condition to $l_2 = \infty$, as the fact of the ends not being free is due to a strain from l_2, and this becomes zero when $l_2 = \infty$. We will find, therefore, the expansion on Fig. 13, and note that it is nearly 11 in.

It is sometimes the practice to use bends. An analysis of the conditions of strain in a 90° bend will show that such a bend has approximately the same strength as a pipe making a 90° turn with an elbow, the two sides of which are each equal to the radius of the bend. There are advantages, however, in the use of the bend—a lessening in the resistance to the flow of the fluid in the pipe, a lessening in the number of fittings used, and, in many cases, a lessening in the cost of the material and erection. In some specifications copper bends are called for, and if the pipe is under a practically constant temperature, these may be fairly satisfactory, even if the stress in the metal is quite large. If the stress is kept fairly well under the elastic limit, steel pipe is, however, as good as copper pipe, and if the elastic limit is nearly reached or exceeded, there is always danger of the breaking of the pipe.

If the pipe is arranged as shown in Fig. 27, and if the expansion is the same on both sides of the loop, the center of the loop will act as a fixed point, and l_1 will be the length of one side of the loop. If now the expansion were altogether on one side of the loop, the entire length of both sides may be taken for l_1, which would appear to make it advantageous to place the loop near an anchorage instead of half way between two anchorages. The reason for this is that by placing the loop near one anchorage, we double the expansion acting on one side of the loop, but we also double l_1, and the expansion permissible varies as $l_1{}^2$ and not as l_1. If, however, the loop is placed half way between the two anchorages, the greatest movement of the pipe at any point is reduced by one-half, and, at times, this may be of considerable importance.

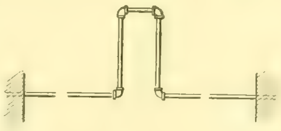

FIG. 27.

The method of using several small pipes or bends in place of one large pipe or bend has been suggested, and can sometimes be used to advantage. The intention is, of course, to make this section of piping capable of greater bending, and, at the same time, not to reduce the

area through which the steam or fluid passes. The combined cross-sectional area of the small pipes may be made equal or larger than that of the large pipe, while the bending will be equal to that of one small pipe.

There is one point in connection with the expansion of pipes, to which particular attention is called. It is possible to reduce greatly the effects of expansion by the use of what is called a cold strain. William J. Baldwin, M. Am. Soc. C. E., was the first, the writer believes, to make use of cold strain in order to reduce the necessary allowance for expansion, and he has gone as far as to put the entire strain in the cold pipe in some cases.

By cold strain is meant the cutting of the pipe in such a manner that the pipe will be strained when cold in exactly the opposite way from that in which it is strained by expansion when hot. If the cold strain is 50% of the normal expansion, the pipe will be strained 50% in what may be called a negative direction when cold, and 50% in the opposite or positive direction when hot. By this means it is possible to reduce the strain in the pipe to half the normal strain of expansion, and thus reduce the necessary allowance for the same in this proportion. There are advantages, however, in making the cold strain greater than 50 per cent. If, for instance, the cold strain is exactly equal to the expansion, then the pipe is under strain when cold and entirely free from strain when hot or, in other words, the tendency to strain open one side of a pipe flange is a maximum when the pipe is cold or when there is no pressure on it, and it becomes zero when the pipe is hot or when there is a maximum pressure on it. The strain of expansion is also eliminated when that due to steam pressure is a maximum, so that the pipe is not subjected to the two strains at the same time.

If the cold strain is something less than the full expansion, these effects are, of course, proportionately decreased.

Perhaps it might be of interest to mention one instance in which the advantage of cold strain was used to remedy what seemed to be a serious trouble. A leak in one of the main steam pipes in a large hotel was causing much annoyance. The cause of the trouble was simply that the flanges were thrown out of line by the strain of the expansion of the piping. The location was such that it was of the utmost importance not to shut off the steam from this pipe for more

than a very short time. Various expedients had been suggested, all requiring a shut-down of the plant for a considerable length of time, when it was suggested by Mr. Baldwin, that one length of flanged pipe be replaced by a similar piece of pipe, cut enough shorter, however, to eliminate entirely the excessive strain of expansion when the piping was hot. This new piece of pipe was made ready before the plant was shut down, and the time, therefore, during which it was not in operation, was limited to a very few minutes.

There is another advantage due to cold strain, which may be mentioned, and which will be appreciated particularly by the steamfitter or the man in charge of the erection of the work, wherever flanged piping is used. The advantage is simply this, that a flange joint when unbolted will tend to open up and allow an easy removal of a gasket.

In conclusion a word may be said in regard to the use of the diagrams. They are calculated for a maximum fiber stress of 12 000 lb. per sq. in. This gives an ample factor of safety for wrought-iron or steel pipe, and more, perhaps, than some will wish to allow. It is very easy, however, to use the diagrams with a higher stress, if so desired, since the stress varies directly as the amount of expansion. If it is desired, for instance, to use a maximum fiber stress of 16 000 lb. per sq. in., it is only necessary to increase the amounts of expansion in the diagrams in the ratio of 16 000 to 12 000, or $\frac{4}{3}$. An expansion of 3 in. in the diagrams can then be made 4 in., and other values can be increased proportionately.

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PAPERS AND DISCUSSIONS

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FEDERAL INVESTIGATIONS OF MINE ACCIDENTS, STRUCTURAL MATERIALS, AND FUELS, AT THE UNITED STATES TESTING STATION, PITTSBURG, PA.

By Herbert M. Wilson, M. Am. Soc. C. E.

To be Presented April 20th, 1910.

Introduction.

The mine disaster, which occurred at Cherry, Ill., on November 13th, 1909, when 527 men were in the mine, resulting in the entombment of 330 men, of whom 310 were killed, has again focused public attention on the frequent recurrence of such disasters and their appalling consequences. Interest in the possible prevention of such disasters, and the possible means of combating subsequent mine fires and rescuing the imprisoned miners, has been heightened as it was not even by the series of three equally extensive disasters which occurred in 1907, for the reason that, after the Cherry disaster, 20 men were rescued alive after an entombment of one week, when practically all hope of rescuing any of the miners had been abandoned.

This accident, occurring, as it does, a little more than $1\frac{1}{2}$ years after the enactment of legislation by Congress instructing the Director of the United States Geological Survey to investigate the causes and possible means of preventing the loss of life in coal-mining

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

operations, makes this an opportune time to review what has been done by the Geological Survey during this time, toward carrying out the intent of this Act.

It may be stated with confidence, that had such a disaster occurred a year or more ago, all the entombed men must have perished, as it would have been impossible to enter the mine without the protection afforded by artificial respiratory apparatus. Moreover, but for the presence of the skilled corps of Government engineers, experienced by more than a year's training in similar operations in more than twenty disasters, the mine would have been sealed until the fire had burned out, and neither the dead, nor those who were found alive, would have been recovered for many weeks. In the interval great suffering and loss would have been inflicted on the miners, because of enforced idleness, and on the mine owners because of continued inability to re-open and resume operations.

Character of the Work.—The United States Geological Survey has been engaged continuously since 1904 in conducting investigations relating to structural materials, such as stone, clay, cement, etc., and in making tests and analyses of the coals, lignites, and other mineral fuel substances, belonging to, and for the use of, the Government.

Incidentally, the Survey has been considering means to increase efficiency in the use of these resources as fuels and structural materials, in the hope that the investigations will lead to their best utilization.

These inquiries attracted attention to the waste of human life incident to the mining of fuel and its preparation for the market, with the result that, in May, 1908, provision was made by Congress for investigations into the causes of mine explosions with a view to their prevention.

Statistics collected by the Geological Survey show that the average death rate in the coal mines of the United States from accidents of all kinds, including gas and dust explosions, falls of roof, powder explosions, etc., is three times that of France, Belgium, and Germany. On the other hand, in no country in the world are natural conditions so favorable for the safe extraction of coal as in the United States. In Belgium, foremost in the study of mining conditions, a constant reduction in the death rate has been secured, and from a rate once nearly as great as that of the United States, namely, 3.28 per thousand, in the period 1851-60, it has been reduced to about 2 per thousand in

the period 1881-90; and in the last decade this has been further reduced to nearly 1 per thousand. It seems certain, from the investigations already made by the Geological Survey, that better means of safeguarding the lives of miners will be found, and that the death rate from mine accidents will soon show a marked reduction.

Other statistics collected by the Geological Survey show that, to the close of 1907, nearly 7 000 000 000 tons of coal had been mined in the United States, and it is estimated that for every ton mined nearly a ton has been wasted, either by being left in the ground or thrown on the dump as of a grade too low for commercial use. To the close of 1907 the production represents an exhaustion of somewhat more than 10 000 000 000 tons of coal. It has been estimated that if the production continues to increase, from the present annual output of approximately 415 000 000 tons, at the rate which has prevailed during the last fifty years, the greater part of the more accessible coal supply will be exhausted before the middle of the next century.

The Forest Service estimates that, at the present rate of consumption, renewals of growth not being taken into account, the timber supply will be exhausted within the next quarter of a century. It is desirable, therefore, that all information possible be gained regarding the most suitable substitutes for wood for building and engineering construction, such as iron, stone, clay products, concrete, etc., and that the minimum proportion in which these materials should be used for a given purpose, be ascertained. Exhaustion, by use in engineering and building construction, applies not only to the iron ore, clay, and cement-making materials, but, in larger ratio, to the fuel essential to rendering these substitutes available for materials of construction. Incidentally, investigations into the waste of structural materials have developed the fact that the destructive losses, due to fires in combustible buildings, amount to more than $200 000 000 per annum. A sum even greater than this is annually expended on fire protection. Inquiries looking to the reduction of fire losses are being conducted in order to ascertain the most suitable fire-resisting materials for building construction.

Early in 1904, during the Louisiana Purchase Exposition, Congress made provision for tests, demonstrations, and investigations concerning the fuels and structural materials of the United States. These investigations were organized subsequently as the Technologic Branch

of the United States Geological Survey, under Mr. Joseph A. Holmes, Expert in Charge, and the President of the United States invited a group of civilian engineers and Chiefs of Engineering Bureaus of the Government to act as a National Advisory Board concerning the method of conducting this work, with a view to making it of more immediate benefit to the Government and to the people of the United States. This Society is formally represented on this Board by C. C. Schneider, Past-President, Am. Soc. C. E., and George S. Webster, M. Am. Soc. C. E. Among representatives of other engineering societies, or of Government Bureaus, the membership of the National Advisory Board includes other members of this Society, as follows: General William Crozier, Frank T. Chambers, Professor W. K. Hatt, Richard L. Humphrey, Robert W. Hunt, H. G. Kelley, Robert W. Lesley, John B. Lober, Hunter McDonald, and Frederick H. Newell.

In view, therefore, of the important part taken both officially and unofficially by members of this Society in the planning and organization of this work, it seems proper to present a statement of the scope, methods, and progress of these investigations. Whereas the Act governing this work limits the testing and investigation of fuels and of structural materials to those belonging to the United States, the activities of the Federal Government in the use of these materials so far exceeds that of any other single concern in the United States, that the results cannot but be of great value to all engineers and to all those engaged in engineering works.

Mine Accidents Investigations.

Organization, and Character of the Work.—The mine rescue investigations, carried on at the Federal testing station, at Pittsburg, Pa., include five lines of attack:

1.—Investigations in the mines to determine the conditions leading up to mine disasters, the presence and the relative explosibility of mine gas and coal dust, and mine fires and means of preventing and combating them.

2.—Tests to determine the relative safety, or otherwise, of the various explosives used in coal mining, when ignited in the presence of explosible mixtures of coal-gas and air, or coal dust, or of both.

3.—Tests to determine the conditions under which electric equipment is safe in coal-mining operations.

4.—Tests to determine the safety of various types of mine lights in the presence of inflammable gas, and their accuracy in detecting small percentages of mine gas.

5.—Tests of the various artificial breathing apparatus, and the training of miners and of skilled mining engineers in rescue methods.

The first four of these lines of investigation have to do with preventative measures, and are those on which ultimately the greatest dependence must be placed. The fifth is one in which the result seems at first to be the most apparent. It has to do, not with prevention, but with the cure of conditions which should not arise, or, at least, should be greatly ameliorated.

During the last 19 years, 28 514 men have been killed in the coal-mining industries. In 1907 alone, 3 125 men lost their lives in coal mines, and, in addition, nearly 800 were killed in the metal mines and quarries of the country. Including the injured, 8 441 men suffered casualties in the mines in that year. In every mining camp containing 1 000 men, 4.86 were taken by violent death in that year. In the mining of coal in Great Britain, 1.31 men were killed in every 1 000 employed in the same year; in France, 1.1; in Belgium, 0.94, or less than 1 man in every 1 000 employed. It is thus seen that from three to four times as many men are being killed in the United States as in any European coal-producing country. This safer condition in Europe has resulted from the use of safer explosives, or the better use of the explosives available; from the reduction in the use of open lights; from the establishment of mine rescue stations and the training with artificial breathing apparatus; and from the adoption of other devices for safeguarding the lives of the workmen.

The mining engineering field force of the Geological Survey, at the head of which is Mr. George S. Rice, an experienced mining and consulting engineer, has already made great progress in the study of underground mining conditions and methods. Nearly every one of the more dangerous mines in the United States has been examined; samples of gas and dust have been taken and analyzed at the chemical laboratories at Pittsburg; extended tests have been made as to the explosibility of various mixtures of gas and air; as to the explosibility of dust from various typical coals; as to the chemical composition and physical characteristics of this dust; the degree of fineness necessary to the most explosive conditions; and the methods of dampening the dust by water, by humidifying, by steam, or of deadening its explosi-

bility by the addition of calcium chloride, stone dust, etc. A bulletin outlining the results thus far obtained in the study of the coal-dust problem is now in course of publication.*

After reviewing the history of observations and experiments with coal dust carried on in Europe, and later, the experiments at the French, German, Belgian, and English explosives-testing stations, this bulletin takes up the coal-dust question in the United States. Further chapters concern the tests as to the explosibility of coal dust, made by the Geological Survey, at Pittsburg; investigations, both at the Pittsburg laboratory and in mines, as to the humidity of mine air. There is also a chapter on the chemical investigations into the ignition of coal dust by Mr. J. C. W. Frazer, of the Geological Survey. The application of some of these data to actual mine conditions in Europe, in the last year, is treated by Mr. Axel Larsen; the use of exhaust steam in a mine of the Consolidation Coal Company, in West Virginia, is discussed by Mr. Frank Haas, Consulting Engineer; and the use of sprays in Oklahoma coal mines is the subject of a chapter by Mr. Carl Scholz, Vice-President of the Rock Island Coal Mining Company.

An earlier bulletin setting forth the literature and certain mine investigations of explosive gases and dust,† has already been issued. After treating of methods of collecting and analyzing the gases found in mines, of investigations as to the rate of liberation of gas from coal, and of studies on coal dust, this bulletin discusses such factors as the restraining influence of shale dust and dampness on coal-dust explosions. It then takes up practical considerations as to the danger of explosions, including the relative inflammability of old and fresh coal dust. The problems involved are undergoing further investigation and elaboration, in the light of information already gathered.

Permissible Explosives.—The most important progress in these tests and investigations has been made in those relating to the various explosives used in getting coal from mines. Immediately upon the enactment of the first legislation, in the spring of 1908, arrangements were perfected whereby the lower portion of the old Arsenal grounds belonging to the War Department and adjacent to the Pennsylvania Railroad, on the Alleghany River, at 40th and Butler Streets, Pittsburg, Pa., were transferred to the Interior Department for use in these

* "The Explosibility of Coal Dust," by George S. Rice. Bulletin No. * * *, U. S. Geological Survey, Washington, D. C.

† "Notes on Explosives, Mine Gases and Dusts," by Rollin Thomas Chamberlin. Bulletin No. 383, U. S. Geological Survey, Washington, D. C., 1909.

investigations. Meantime, in anticipation of the appropriation, Mr. Clarence Hall, an engineer experienced in the manufacture and use of explosives, was sent to Europe to study the methods of testing explosives practiced at the Government stations in Great Britain, Germany, Belgium, and France. Mr. Joseph A. Holmes also visited Europe for the purpose of studying methods of ameliorating conditions in the mines. Under the supervision of the writer, Chief Engineer of these investigations, detailed plans and specifications had been prepared in advance for the necessary apparatus, and the transformation of the buildings at Pittsburg to the purposes of this work. It was possible, therefore, to undertake immediately the changes in existing buildings, the erection of new buildings, the installation of railway tracks, laboratories, and the plumbing, heating, and lighting plant, etc. This work was carried on with unusual expedition, under the direction of the Assistant Chief Engineer, Mr. James C. Roberts, and was completed within a few months, by which time most of the apparatus was delivered and installed.

One building (No. 17) is devoted to the smaller physical tests of explosives. It was rendered fire resistant by heavily covering the floors, ceiling, and walls with cement on metal lath, and otherwise protecting the openings. In it are installed apparatus for determining calorific value of explosives, pressure produced on ignition, susceptibility to ignition when dropped, rate of detonation, length and duration of flame, and kindred factors. Elsewhere on the grounds is a gallery of boiler-steel plate, 100 ft. long and more than 6 ft. in diameter, solidly attached to a mass of concrete at one end, in which is embedded a cannon from which to discharge the explosive under test, and open at the other end, and otherwise so constructed as to simulate a small section of a mine gallery (Fig. 1, Plate XLIX). The heavy mortar pendulum, for the pendulum test for determining the force produced by an explosive, is near by, as is also an armored pit in which large quantities of explosive may be detonated with a view to studying the effects of magazine explosions, and for testing as to the rate at which ignition of an explosive travels from one end to the other of a cartridge, and the sensitiveness of one cartridge to explosion by discharge of another near by.

In another building (No. 21), is a well-equipped fire-proof chemical laboratory for chemical analyses and investigations of explosives, structural materials, and fuels.

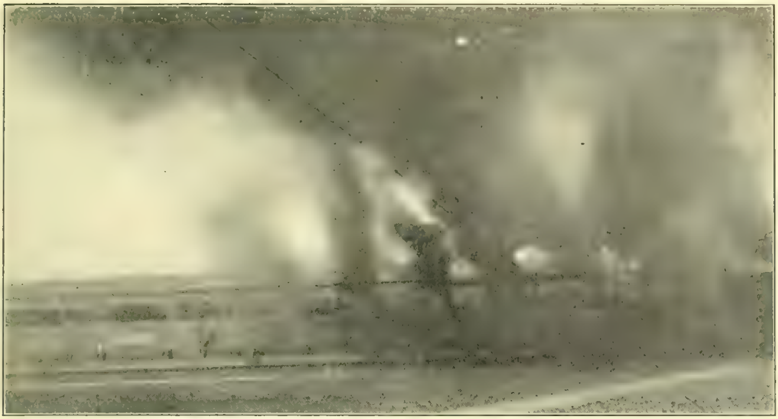


FIG. 1. EXPLOSION FROM COAL DUST IN GAS AND DUST GALLERY NO. 1.

FIG. 2.—MINE GALLERY NO. 1.

FIG. 3.—BALLISTIC PENDULUM.

Several months were required to calibrate the various apparatus, and to make analyses of the available natural gas to determine the correct method of proportioning it with air, so as to produce exact mixtures of 2, 4, 6, or 8% of methane with air. Tests of existing explosives were made in air and in inflammable mixtures of air and gas, with a view to fixing on some standard explosive as a basis of comparison. Ultimately, 45% of nitro-glycerine dynamite was adopted as the standard. Investigative tests having been made, and the various factors concerning all the explosives on the market having been determined, a circular was sent to all manufacturers of explosives in the United States, on January 9th, 1909, and was also published in the various technical journals, through the associated press, and otherwise.

On May 15th, 1909, all the explosives which had been offered for test, as permissible, having been tested, the first list of permissible explosives was issued, as given in the following circular:

"EXPLOSIVES CIRCULAR NO. 1.

"DEPARTMENT OF THE INTERIOR.
"UNITED STATES GEOLOGICAL SURVEY.
"MAY 15, 1909.

"LIST OF PERMISSIBLE EXPLOSIVES.

"Tested prior to May 15, 1909.

"As a part of the investigation of mine explosions authorized by Congress in May, 1908, it was decided by the Secretary of the Interior that a careful examination should be made of the various explosives used in mining operations, with a view to determining the extent to which the use of such explosives might be responsible for the occurrence of these disasters.

"The preliminary investigation showed the necessity of subjecting to rigid tests all explosives intended for use in mines where either gas or dry inflammable dust is present in quantity or under conditions which are indicative of danger.

"With this in view, a letter was sent by the Director of the United States Geological Survey on January 9, 1909, to the manufacturers of explosives in the United States, setting forth the conditions under which these explosives would be examined and the nature of the tests to which they would be subjected.

"Inasmuch as the conditions and tests described in this letter were subsequently followed in testing the explosives given in the list below, they are here reproduced, as follows:

"(1) The manufacturer is to furnish 100 pounds of each explosive which he desires to have tested; he is to be responsible for the care, handling, and delivery of this material at the testing station on the

United States arsenal grounds, Fortieth and Butler streets, Pittsburg, Pa., at the time the explosive is to be tested; and he is to have a representative present during the tests, who will be responsible for the handling of the packages containing the explosives until they are opened for testing.

"(2) No one is to be present at or to participate in these tests except the necessary government officers at the testing station, their assistants, and the representative of the manufacturer of the explosives to be tested.

"(3) The tests will be made in the order of the receipt of the applications for them, provided the necessary quantity of the explosive is delivered at the plant by the time assigned, of which due notice will be given by the Geological Survey.

"(4) Preference will be given to the testing of explosives that are now being manufactured and that are in that sense already on the market. No test will be made of any new explosive which is not now being manufactured and marketed, until all explosives now on the market that may be offered for testing have been tested.

"(5) A list of the explosives which pass certain requirements satisfactorily will be furnished to the state mine inspectors, and will be made public in such further manner as may be considered desirable.

"TEST REQUIREMENTS FOR EXPLOSIVES.

"The tests will be made by the engineers of the United States Explosives Testing Station at Pittsburg, Pa., in gas and dust gallery No. 1. The charge of explosive to be fired in tests 1, 2, and 3 shall be equal in disruptive power to one-half pound (227 grams) of 40 per cent. nitroglycerin dynamite in its original wrapper, of the following formula:

Nitroglycerin	40
Nitrate of sodium	44
Wood pulp	15
Calcium carbonate	1
	100

"Each charge shall be fired with an electric fuse of sufficient power to completely detonate or explode the charge, as recommended by the manufacturer. The explosive must be in such condition that the chemical and physical tests do not show any unfavorable results. The explosives in which the charge used is less than 100 grams (0.22 pound) will be weighed in tinfoil without the original wrapper.

"The dust used in tests 2, 3, and 4 will be of the same degree of fineness and taken from one mine.*

"TEST 1.—Ten shots with the charge as described above, in its original wrapper, shall be fired, each with 1 pound of clay tamping, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent. of methane and ethane. An explosive will pass this test if all ten shots fail to ignite the mixture.

"TEST 2.—Ten shots with charge as previously noted, in its original wrapper, shall be fired, each with 1 pound of clay tamping at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per

* With a view to obtaining a dust of uniform purity and inflammability.

cent. of methane and ethane and 20 pounds of bituminous coal dust, 18 pounds of which is to be placed on shelves laterally arranged along the first 20 feet of the gallery, and 2 pounds to be placed near the inlet of the mixing system in such a manner that all or part of it will be suspended in the first division of the gallery. An explosive will pass this test if all ten shots fail to ignite the mixture.

"TEST 3.—Ten shots with charge as previously noted, in its original wrapper, shall be fired, each with 1 pound of clay tamping at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 20 pounds of which is to be distributed uniformly on a horse placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive will pass this test if all ten shots fail to ignite the mixture.

"TEST 4.—A limit charge will be determined within 25 grams by firing charges in their original wrappers, untamped, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent. of methane and ethane and 20 pounds of bituminous coal dust, to be arranged in the same manner as in test 2. This limit charge is to be repeated five times under the same conditions before being established.

"NOTE.—At least 2 pounds of clay tamping will be used with slow-burning explosives.

"WASHINGTON, D. C., *January 9, 1909.*

"In response to the above communication applications were received from 12 manufacturers for the testing of 29 explosives. Of these explosives, the 17 given in the following list have passed all the test requirements set forth, and will be termed permissible explosives.

"Permissible explosives tested prior to May 15, 1909.

Brand.	Manufacturer.
Ætna coal powder A....	Ætna Powder Co., Chicago, Ill.
Ætna coal powder B....	Do.
Carbonite No. 1........	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Carbonite No. 2........	Do.
Carbonite No. 3........	Do.
Carbonite No. 1 L. F....	Do.
Carbonite No. 2 L. F....	Do.
Coal special No. 1......	Keystone Powder Co., Emporium, Pa.
Coal special No. 2......	Do.
Coalite No. 1..........	Potts Powder Co., New York City.
Coalite No. 2 D........	Do.
Collier dynamite No. 2..	Sinnamahoning Powder Co., Emporium, Pa.
Collier dynamite No. 4..	Do.
Collier dynamite No. 5..	Do.
Masurite M. L. F.......	Masurite Explosive Co., Sharon, Pa.
Meteor dynamite........	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Monobel	Do.

"Subject to the conditions named below, a permissible explosive is defined as an explosive which has passed gas and dust gallery tests Nos. 1, 2, and 3 as described above, and of which in test No. 4 1½ pounds (680 grams) of the explosive has been fired into the mixture there described without causing an ignition.

"*Provided:*

"1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.

"2. That double-strength detonators are used of not less strength than 1 gram charge consisting by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or its equivalent), except for the explosive 'Masurite M. L. F.,' for which the detonator shall be of not less strength than 1½ grams charge.

"3. That the explosive, if in a frozen condition, shall be thoroughly thawed in a safe and suitable manner before use.

"4. That the amount used in practice does not exceed 1½ pounds (680 grams) properly tamped.

"The above partial list includes the permissible explosives that have passed these tests prior to May 15, 1909. The announcement of the passing of like tests by other explosives will be made public immediately after the completion of the tests for such explosives.

"A description of the method followed in making these and the many additional tests to which each explosive is subjected, together with the full data obtained in each case, will be published by the Survey at an early date.

"NOTES AND SUGGESTIONS.

"It may be wise to point out in this connection certain differences between the permissible explosives as a class and the black powders now so generally used in coal mining, as follows:

"(*a*) With equal quantities of each, the flame of the black powder is more than three times as long and has a duration three thousand to more than four thousand times that of one of the permissible explosives, also the rate of explosion is slower.

"(*b*) The permissible explosives are one and one-fourth to one and three-fourths times as strong and are said, if properly used, to do twice the work of black powder in bringing down coal; hence only half the quantity need be used.

"(*c*) With 1 pound of a permissible explosive or 2 pounds of black powder, the quantity of noxious gases given off from a shot averages approximately the same, the quantity from the black powder being less than from some of the permissible explosives and slightly greater than from others. The time elapsing after firing before the miner returns to the working face or fires another shot should not be less for permissible explosives than for black powder.

"The use of permissible explosives should be considered as supplemental to and not as a substitute for other safety precautions in mines where gas or inflammable coal dust is present under conditions indicative of danger. As stated above, they should be used with strong detonators; and the charge used in practice should not exceed 1½ pounds, and in many cases need not exceed 1 pound.

"Inasmuch as no explosive manufactured for use in mining is flameless, and as no such explosive is entirely safe under all the variable mining conditions, the use of the terms 'flameless' and 'safety' as applied to explosives is likely to be misunderstood, may endanger human life, and should be discouraged.

"JOSEPH A. HOLMES,
"Expert in Charge Technologic Branch.

"Approved, May 18, 1909:
"GEO. OTIS SMITH,
"Director."

In the meantime, many of the explosives submitted, which heretofore had been on the market as safety explosives, were found to be unsafe for use in gaseous or dusty mines, and the manufacturers were permitted to withdraw them. Their weaknesses being known, as a result of these tests, the manufacturers were enabled to produce similar, but safer, explosives. Consequently, applications for further tests continued to pour in, as they still do, and on October 1st, 1909, a second list of permissible explosives was issued, as follows:

"EXPLOSIVES CIRCULAR NO. 2.

"DEPARTMENT OF THE INTERIOR.

"UNITED STATES GEOLOGICAL SURVEY.

"OCTOBER 1, 1909.

"LIST OF PERMISSIBLE EXPLOSIVES.

"Tested prior to October 1, 1909.

"The following list of permissible explosives tested by the United States Geological Survey at Pittsburg, Pa., is hereby published for the benefit of operators, mine owners, mine inspectors, miners, and others interested.

"The conditions and test requirements described in Explosives Circular No. 1, issued under date of May 15, 1909, have been followed in all subsequent tests.

"Subject to the provisions named below, a permissible explosive is defined as an explosive which is in such condition that the chemical and physical tests do not show any unfavorable results; which has passed gas and dust gallery tests Nos. 1 and 3, as described in circular

No. 1; and of which, in test No. 4, 1½ pounds (680 grams) has been fired into the mixture there described without causing ignition.

"*Permissible explosives tested prior to October 1, 1909.*

"[Those reported in Explosives Circular No. 1 are marked *.]

Brand.	Manufacturer.
*Ætna coal powder A	Ætna Powder Co., Chicago, Ill.
Ætna coal powder AA	Do.
*Ætna coal powder B	Do.
Ætna coal powder C	Do.
Bituminite No. 1	Jefferson Powder Co., Birmingham, Ala.
Black Diamond No. 3	Illinois Powder Manufacturing Co., St. Louis, Mo.
Black Diamond No. 4	Do.
*Carbonite No. 1	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
*Carbonite No. 2	Do.
*Carbonite No. 3	Do.
*Carbonite No. 1-L. F.	Do.
*Carbonite No. 2-L. F.	Do.
*Coalite No. 1	Potts Powder Co., New York City.
*Coalite No. 2-D	Do.
*Coal special No. 1	Keystone Powder Co., Emporium, Pa.
*Coal special No. 2	Do.
*Collier dynamite No. 2	Sinnamahoning Powder Manufacturing Co., Emporium, Pa.
*Collier dynamite No. 4	Do.
*Collier dynamite No. 5	Do.
Giant A low-flame dynamite	Giant Powder Co. (Con.) Giant, Cal.
Giant B low-flame dynamite	Do.
Giant C low-flame dynamite	Do.
*Masurite M. L. F	Masurite Explosives Co., Sharon, Pa.
*Meteor dynamite	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Mine-ite A	Burton Powder Co., Pittsburg, Pa.
Mine-ite B	Do.
*Monobel	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Tunnelite No. 5	G. R. McAbee Powder and Oil Co., Pittsburg, Pa.
Tunnelite No. 6	Do.
Tunnelite No. 7	Do.
Tunnelite No. 8	Do.

"*Provided:*

"1. That the explosive is in all respects similar to sample submitted by the manufacturer for test.

"2. That No. 6 detonators, preferably No. 6 electric detonators (double strength), are used of not less strength than 1 gram charge, consisting by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or its equivalent), except for the explosive 'Masurite M. L. F.,' for which the detonator shall be of not less strength than 1½ grams charge.

"3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

"4. That the amount used in practice does not exceed 1½ pounds (680 grams), properly tamped.

"The above partial list includes all the permissible explosives that have passed these tests prior to October 1, 1909. The announcement of the passing of like tests by other explosives will be made public immediately after the completion of the tests.

"With a view to the wise use of these explosives it may be well in this connection to point out again certain differences between the permissible explosives as a class and the black powders now so generally used in coal mining, as follows:

"(*a*) With equal quantities of each, the flame of the black powder is more than three times as long and has a duration three thousand to more than four thousand times that of one of the permissible explosives; the rate of explosion also is slower.

"(*b*) The permissible explosives are one and one-fourth to one and three-fourths times as strong and are said, if properly used, to do twice the work of black powder in bringing down coal; hence only half the quantity need be used.

"(*c*) With 1 pound of a permissible explosive or 2 pounds of black powder, the quantity of noxious gases given off from a shot averages approximately the same, the quantity from the black powder being less than from some of the permissible explosives and slightly greater than from others. The time elapsing after firing before the miner returns to the working face or fires another shot should not be less for permissible explosives than for black powder.

"The use of permissible explosives should be considered as supplemental to and not as a substitute for other safety precautions in mines where gas or inflammable coal dust is present under conditions indicating danger. As stated above, they should be used with strong detonators, and the charge used in practice should not exceed 1½ pounds and in many cases need not exceed 1 pound.

"JOSEPH A. HOLMES,
"Expert in Charge Technologic Branch.

"Approved, October 11, 1909.
"H. C. RIZER,
"Acting Director."

The second list contains 31 explosives which the Government is prepared to brand as permissible, and therefore comparatively safe for use in gaseous and dusty mines. An equally large number of so-called safety powders failed to pass these tests. Immediately on the passing of the tests, as to the permissibility of any explosive, the facts are reported to the manufacturer and to the various State mine inspectors. When published, the permissible lists were issued to all explosives manufacturers, all mine operators in the United States, and State inspectors. The effect has been the enactment, by three of the largest coal-producing States, of legislation or regulations prohibiting the use of any but permissible explosives in gaseous or dusty mines, and other States must soon follow. To prevent fraud the Geological Survey has copyrighted and authorized the use of the brand "Permissible Explosive, U. S. Testing Station, Pittsburg, Pa.," to be placed on all boxes or packages containing listed permissible explosives.

As these tests clearly demonstrate, both in the records thereof and visually to such as follow them, certain explosives, especially those which are slow-burning like black powder, or produce high temperatures in connection with comparative slow burning, will ignite mixtures of gas and air, or mixtures of coal dust and air, and cause explosions. The results point out clearly to all concerned, the danger of using such explosives. The remedy is also made available by the announcement of the names of a large number of explosives now on the market at reasonable cost, which will not cause explosions under these conditions. It is believed that when permissible explosives are generally adopted in coal mines, this source of danger will have been greatly minimized.

Explosives Investigations.—Questions have arisen on the part of miners or of mine operators as to the greater cost in using permissible explosives due to their expense, which is slightly in excess of that of other explosives; as to their greater shattering effect in breaking down the coal, and in giving a smaller percentage of lump and a larger percentage of slack; and as to the possible danger of breathing the gases produced.

Observations made in mines by Mr. J. J. Rutledge, an experienced coal miner and careful mining engineer connected with the Geological Survey, as to the amount of coal obtained by the use of permissible and other explosives, tend to indicate that the permissible explosives

are not more, but perhaps less expensive than others, in view of the fact that, because of their greater relative power, a smaller quantity is required to do the work than is the case, say, with black powder. On the other hand, for safety and for certainty of detonation, stronger detonators are recommended for use with permissible explosives, preferably electric detonators. These may cost a few cents more per blast than the squib or fuse, but there is no danger that they will ignite the gas, and the difference in cost is, in some measure, offset by the greater certainty of action and the fact that they produce a much more powerful explosion, thus again permitting the use of still smaller quantities of the explosive and, consequently, reducing the cost. These investigations are still in progress.

Concerning the shattering of the coal: This is being remedied in some of the permissible explosives by the introduction of dopes, moisture, or other means of slowing down the disruptive effect, so as to produce the heaving and breaking effect obtained with the slower-burning powders instead of the shattering effect produced by dynamite. There is every reason to believe that as the permissible explosives are perfected, and as experience develops the proper methods of using them, this difficulty will be overcome in large measure. This matter is also being investigated by the Survey mining engineers and others, by the actual use of such explosives in coal-mining operations.

Of the gases given off by explosives, those resulting from black powder are accompanied by considerable odor and smoke, and, consequently, the miners go back more slowly after the shots, allowing time for the gases to be dissipated by the ventilation. With the permissible explosive, the miner, seeing no smoke and observing little odor, is apt to be incautious, and to think that he may run back immediately. As more is learned of the use of these explosives, this source of danger, which is, however, inconsiderable, will be diminished. Table 1 gives the percentages of the gaseous products of combustions from equal weights of black powder and two of the permissible explosives. Of the latter, one represents the maximum amount of injurious gases, and the other the minimum amount, between which limits the permissible explosives approximately vary.

Such noxious gases as may be produced by the discharge of the explosive, are diluted by a much larger volume of air, and are prac-

tically harmless, as proven by actual analysis of samples taken at the face immediately after a discharge.

TABLE 1.

	Black powder.	Permissible Explosives.	
		Maximum.	Minimum.
CO_2	22.8	14.50	21.4
CO	10.3	27.74	1.3
N........................	10.3	45.09	74.4

In addition to investigations as to explosives for use in coal mining, the Explosives Section of the Geological Survey analyzes and tests all such materials, fuses, caps, etc., purchased by the Isthmian Canal Commission, as well as many other kinds used by the Government. It is thus acquiring a large fund of useful information, which will be published from time to time, relative to the kinds of explosives and the manner of using them best suited to any blasting operations, either above or under water, in hard rock, dirt, or coal. There is about to be issued from the press, a primer of explosives,* by Mr. Clarence Hall, the engineer in charge of these tests, and Professor C. E. Munroe, Consulting Explosives Chemist, which contains a large amount of valuable fundamental information, so simply expressed as to be easily understandable by coal miners, and yet sufficiently detailed as to be a valuable guide to all persons who have to handle or use explosives.

In the first chapters are described the various combustible substances, and the chemical reactions leading to their explosibility. The low and high explosives are differentiated, and the sensitiveness of fulminate of mercury and other detonators is clearly pointed out. The various explosives, such as gunpowder, black blasting powder, potassium chlorate powders, nitro-glycerine powders, etc., are described, and their peculiarities, and suitability for different purposes, are set forth. The character and method of using the different explosives, both in opening up work and in enclosed work in coal mines, follow, with information as to the proper method of handling, transporting,

* "The Primer of Explosives," by C. E. Munroe and Clarence Hall. Bulletin No. 423, U. S. Geological Survey, Washington, D. C., 1909.

storing, and thawing the same. Then follow chapters on squibs, fuses, and detonators; on methods of shooting coal off the solid; location of bore-holes; undercutting; and the relative advantages of small and large charges, with descriptions of proper methods of loading and firing the same. The subjects of explosives for blasting in rock, firing machines, blasting machines, and tests thereof, conclude the report.

The work of the chemical laboratory in which explosives are analyzed, and in which mine gases and the gases produced by combustion of explosives and explosions of coal-gas or coal dust are studied, has been of the most fundamental and important character. The Government is procuring a confidential record of the chemical composition and mode of manufacture of all explosives, fuses, etc., which are on the market. This information cannot but add greatly to the knowledge as to the chemistry of explosives for use in mines, and will furnish the basis on which remedial measures may be devised.

A bulletin (shortly to go to press) which gives the details of the physical tests of the permissible explosives thus far tested, will set forth elaborately the character of the testing apparatus, and the method of use and of computing results.*

This bulletin contains a chapter, by Mr. Rutledge, setting forth in detail the results of his observations as to the best methods of using permissible explosives in getting coal from various mines in which they are used. This information will be most valuable in guiding mining engineers who desire to adopt the use of permissible explosives, as to the best methods of handling them.

Electricity in Mines.—In connection with the use of electricity in mines, a complete series of tests has been made on all enclosed electric fuses, as to whether or not they will ignite an explosive mixture of air and gas when blown out. The results of this work, which is under the direction of Mr. H. H. Clark, Electrical Engineer for Mines, have been furnished the manufacturers for their guidance in perfecting safer fuses. A series of tests as to the ability of the insulation of electric wiring to withstand the attacks of acid mine waters is in progress, which will lead, it is hoped, to the development of more permanent and cheaper insulation for use in mine wiring. A series of competitive tests of enclosed motors for use in mines

* "Tests of Permissible Explosives," by Clarence Hall, W. O. Snelling, and S. P. Howell. Bulletin No. * * *, U. S. Geological Survey, Washington, D. C.

has been announced, and is in progress, the object being to determine whether or not sparking from such motors will cause an explosion in the presence of inflammable gas.

In the grounds outside of Building No. 10 is a large steel gallery, much shorter than Gallery No. 1, in fact, but 30 ft. in length, and much greater in diameter, namely, 10 ft., in which electric motors, electric cutting machines, and similar apparatus, are being tested in the presence of explosive mixtures of gas and dust and with large amperage and high voltage, such as may be used in the largest electrical equipment in mines.

The investigation as to the ability of insulation to withstand the effects of acid mine waters has been very difficult and complicated. At first it was believed possible that mine waters from nearby Pennsylvania mines and of known percentages of acidity could be procured and kept in an immersion tank at approximately any given percentage of strength. This was found to be impracticable, as these waters seem to undergo rapid change the moment they are exposed to the air or are transported, in addition to the changes wrought by evaporation in the tank. It has been necessary, therefore, to analyze and study carefully these waters with a view to reproducing them artificially for the purpose of these tests. Concerning the insulation, delicate questions have arisen as to a standard of durability which shall be commensurate with reasonable cost. These preliminary points are being solved in conference with the manufacturers, and it is expected that the results will soon be published.

Safety-Lamp Investigations.—Many so-called safety lamps are on the market, and preliminary tests of them have been made in the lamp gallery, in Building No. 17. After nearly a year of endeavor to calibrate this gallery, and to co-ordinate its results with those produced in similar galleries in Europe, this preliminary inquiry has been completed, and the manufacturers and agents of all safety lamps have been invited to be present at tests of their products at the Pittsburg laboratory.

A circular dated November 19th, 1909, contains an outline of these tests, which are to be conducted under the direction of Mr. J. W. Paul, an experienced coal-mining engineer and ex-Chief of the Department of State Mine Inspection of West Virginia. The lamps will be subjected to the following tests:

(*a*).—Each lamp will be placed in a mixture of air and explosive natural gas containing 6, 8, and 10% of gas, moving at a velocity of from 200 to 2 500 ft. per min., to determine the velocity of the air current which will ignite the mixture surrounding the lamp. The current will be made to move against the lamp in a horizontal, vertical ascending, and vertical descending direction, and at an angle of 45°, ascending and descending.

(*b*).—After completing the tests herein described, the lamps will be subjected to the tests described under (*a*), with the air and gas mixture under pressure up to 6 in. of water column.

(*c*).—Under the conditions outlined in (*a*), coal dust will be introduced into the current of air and gas to determine its effect, if any, in inducing the ignition of the gas mixture.

(*d*).—Each lamp will be placed in a mixture of air and varying percentages of explosive natural gas to determine the action of the gas on the flame of the lamp.

(*e*).—Each lamp will be placed in a mixture of air and varying percentages of carbonic acid gas to determine the action of the gas on the flame.

(*f*).—Lamps equipped with internal igniters will be placed in explosive mixtures of air and gas in a quiet state and in a moving current, and the effect of the igniter on the surrounding mixture will be observed.

(*g*).—The oils (illuminants) used in the lamps will be tested as to viscosity, gravity, flashing point, congealing point, and composition.

(*h*).—Safety-lamp globes will be tested by placing each globe in position in the lamp and allowing the flame to impinge against the globe for 3 min. after the lamp has been burning with a full flame for 10 min., to determine whether the globe will break.

(*i*).—Each safety-lamp globe will be mounted in a lighted lamp with up-feed, and placed for 5 min. in an explosive mixture of air and gas moving at the rate of 1 000 ft. per min., to determine whether the heat will break the glass and, if it is broken, to note the character of the fracture.

(*j*).—Safety-lamp globes will be broken by impact, by allowing each globe to fall and strike, horizontally, on a block of seasoned white oak, the distance of fall being recorded.

(*k*).—Each safety lamp globe will be mounted in a safety lamp

and, when the lamp is in a horizontal position, a steel pick weighing 100 grammes will be permitted to fall a sufficient distance to break the globe by striking its center, the distance of the fall to be recorded.

(*l*).—To determine the candle-power of safety lamps, a photometer equipped with a standardized lamp will be used. The candle-power will be determined along a line at right angles to the axis of the flame; also along lines at angles to the axis of the flame both above and below the horizontal. The candle-power will be read after the lamp has been burning 20 min.

(*m*).—The time a safety lamp will continue to burn with a full charge of illuminant will be determined.

(*n*).—Wicks in lamps must be of sufficient length to be at all times in contact with the bottom of the vessel in which the illuminant is contained, and, before it is used, the wick shall be dried to remove moisture.

Mine-Rescue Methods.—Mr. Paul, who has had perhaps as wide an experience as any mining man in the investigation of and in rescue work at mine disasters, is also in charge of the mine-rescue apparatus and training for the Geological Survey. These operations consist chiefly of a thorough test of the various artificial breathing apparatus, or so-called oxygen helmets. Most of these are of European make and find favor in Great Britain, Belgium, France, or Germany, largely according as they are of domestic design and manufacture. As yet nothing has been produced in the United States which fulfills all the requirements of a thoroughly efficient and safe breathing apparatus for use in mine disasters.

At the Pittsburg testing station there are a number of all kinds of apparatus. The tests of these are to determine ease of use, of repair, durability, safety under all conditions, period during which the supply of artificial air or oxygen can be relied on, and other essential data.

In addition to the central testing station, sub-stations for training miners, and as headquarters for field investigation as to the causes of mine disasters and for rescue work in the more dangerous coal fields, have been established: at Urbana, Ill., in charge of Mr. R. Y. Williams, Mining Engineer; at Knoxville, Tenn., in charge of Mr. L. M. Jones, Assistant Mining Engineer; and at

Seattle, Wash., in charge of Mr. Hugh Wolflin, Assistant Mining Engineer. Others may soon be established in Colorado and Oklahoma, in charge of skilled mining engineers who have been trained in this work at Pittsburg, and who will be assisted by trained miners. It is not to be expected that under any but extraordinary circumstances, such as those which occurred at Cherry, Ill., the few Government rescue men, located at widely scattered points throughout the United States, can hope to save the lives of miners after a disaster occurs. As a rule, all who are alive in the mine on such an occasion, are killed within a few minutes. This is almost invariably the case after a dust explosion, and is likely to be true after a gas explosion, although a fire such as that at Cherry, Ill., offers the greatest opportunity for subsequent successful rescue operations. The most to be hoped for from the Government engineers is that they shall train miners and be available to assist and advise State inspectors and mine owners, should their services be called for.

It should be borne in mind that the Federal Government has no police duties in the States, and that, therefore, its employees may not direct operations or have other responsible charge in the enforcement of State laws. There is little reason to doubt that these Federal mining engineers, both because of their preliminary education as mining engineers and their subsequent training in charge of mine operations, and more recently in mine-accidents investigations and rescue work, are eminently fitted to furnish advice and assistance on such occasions. The mere fact that, within a year, some of these men have been present at, and assisted in, rescue work or in opening up after disasters at nearly twenty of such catastrophes, whereas the average mining engineer or superintendent may be connected with but one in a lifetime, should make their advice and assistance of supreme value on such occasions. They cannot be held in any way responsible for tardiness, however, nor be unduly credited with effective measures taken after a mine disaster, because of their lack of responsible authority or charge, except in occasional instances where such may be given them by the mine owners or the State officials, from a reliance on their superior equipment for such work.

Successful rescue operations may only be looked for when the time, now believed to be not far distant, has been reached when the mine operators throughout the various fields will have their own

rescue stations, as is the practice in Europe, have available, at certain strategic mines, the necessary breathing apparatus, and have in their employ skilled miners who have been trained in rescue work at the Government stations. Then, on the occurrence of a disaster, the engineer in charge of the Government station may notify by wire all those who have proper equipment or training to assemble, and it may be possible to gather, within an hour or two of a disaster, a sufficiently large corps of helmet-men to enable them to recover such persons as have not been killed before the fire—which usually is started by the explosion—has gained sufficient headway to prevent entrance into the mine. Without such apparatus, it is essential that the fans be started, and the mine cleared of gas. The usual effect of this is to give life to any incipient fire. With the apparatus, the more dense the gas, the safer the helmet-men are from a secondary explosion or from the rapid ignition of a fire, because of the absence of the oxygen necessary to combustion.

The miners who were saved at Cherry, Ill., on November 20th, 1909, owe their lives primarily to the work of the Government's rescue corps. The sub-rescue station of the Survey at Urbana, Ill., was promptly notified of the disaster on the afternoon of November 13th. Arrangements were immediately made, whereby Mr. R. Y. Williams, Mining Engineer in Charge, and his Assistant, Mr. J. M. Webb, with their apparatus, were rushed by special train to the scene, arriving early the following day (Sunday).

Chief Mining Engineer, George S. Rice; Chief of Rescue Division, J. W. Paul, and Assistant Engineer, F. F. Morris, learned of the disaster through the daily press, at their homes in Pittsburg, on Sunday. They left immediately with four sets of rescue apparatus, reaching Cherry on Monday morning. Meantime, Messrs. Williams and Webb, equipped with oxygen helmets, had made two trips into the shaft, but were driven out by the heat. Both shafts were shortly resealed with a view to combating the fire, which had now made considerable headway.

The direction of the operations at Cherry, was, by right of jurisdiction, in charge of the State Mine Inspectors of Illinois, at whose solicitation the Government engineers were brought into conference as to the proper means to follow in an effort to get into the mine. The disaster was not due to an explosion of coal or gas, but was the re-

sult of a fire ignited in hay, in the stable within the mine. The flame had come through the top of the air-shaft, and had disabled the ventilating fans. A rescue corps of twelve men, unprotected by artificial breathing apparatus, had entered the mine, and all had been killed. When the shafts were resealed on Monday evening, the 15th, a small hole was left for the insertion of a water-pipe or hose. During the afternoon and evening, a sprinkler was rigged up, and, by Tuesday morning, was in successful operation, the temperature in the shaft at that time being 109° Fahr. After the temperature had been reduced to about 100°, the Federal engineers volunteered to descend into the shaft and make an exploration. The rescue party, equipped with artificial breathing apparatus, consisting of Messrs. Rice, Paul, and Williams, made an exploration near the bottom of the air-shaft and located the first body. After they had returned to the surface, three of the Illinois State Inspectors, who had previously received training by the Government engineers in the use of the rescue apparatus, including Inspectors Moses and Taylor, descended, made tests of the air, and found that with the fan running slowly, it was possible to work in the shaft. The rescue corps then took hose down the main shaft, having first attached it to a fire engine belonging to the Chicago Fire Department. Water was directed on the fire at the bottom of the shaft, greatly diminishing its force, and it was soon subdued sufficiently to permit the firemen to enter the mine without the protection of breathing apparatus.

Unfortunately, these operations could be pursued only under the most disadvantageous circumstances and surrounded by the greatest possible precautions, due to the frequent heavy falls of roof—a result of the heating by the mine fire—and the presence of large quantities of black-damp. All movements of unprotected rescuers had to be preceded by exploration by the trained rescue corps, who analyzed the gases, as the fire still continued to burn, and watched closely for falls, possible explosions, or a revival of the fire. While the heavy work of shoring up and removing bodies was being carried on by the unprotected rescue force, the helmet-men explored the more distant parts of the mine, and on Saturday afternoon, November 20th, one week after the disaster, a room was discovered in which a number of miners, with great presence of mind, had walled themselves in in order to keep out the smoke and heat. From this room 20 living men

were taken, of whom 12 were recovered in a helpless condition, by the helmet-men.

This is not the first time this Government rescue corps has performed valiant services. Directly and indirectly the members have saved from fifteen to twenty lives in the short time they have been organized. At the Marianna, Pa., disaster, the corps found one man still alive among 150 bodies, and he was brought to the surface. He recovered entirely after a month in the hospital.

At the Leiter mine, at Zeigler, Ill., two employees, who had been trained in the use of the oxygen helmets by members of the Government's corps, went down into the mine, following an explosion, and brought one man to the surface, where they resuscitated him.

Equally good service, either in actual rescue operations, or in explorations after mine disasters, or in fire-fighting, has been rendered by this force at the Darr, Star Junction, Hazel, Clarinda, Sewickley, Berwind-White No. 37, and Wehrum, Pa., mine disasters; at Monongah and Lick Branch, W. Va.; at Deering, Sunnyside, and Shelburn, Ind., Jobs, Ohio, and at Roslyn, Wash.

Explosives Laboratory.—The rooms grouped at the south end of Building No. 21, at Pittsburg, are occupied as a laboratory for the chemical examination and analysis of explosives, and are in charge of Mr. W. O. Snelling.

Samples of all explosives used in the testing gallery, ballistic pendulum, pressure gauge, and other testing apparatus, are here subjected to chemical analysis in order to determine the component materials and their exact percentages. Tests are also made to determine the stability of the explosive, or its liability to decompose at various temperatures, and other properties which are of importance in showing the factors which will control the safety of the explosive during transportation and storage.

In the investigation of all explosives, the first procedure is a qualitative examination to determine what constituents are present. Owing to the large number of organic and inorganic compounds which enter into the composition of explosive mixtures, this examination must be thorough. Several hundred chemical bodies have been used in explosives at different times, and some of these materials can be separated from others with which they are mixed only by the most careful and exact methods of chemical analysis.

Following the qualitative examination, a method is selected for the separation and weighing of each of the constituents previously found to be present. These methods, of course, vary widely, according to the particular materials to be separated, it being usually necessary to devise a special method of analysis for each explosive, unless it is found, by the qualitative analysis, to be similar to some ordinary explosive, in which case the ordinary method of analysis of that explosive can be carried out. Most safety powders require special treatment, while most grades of dynamite and all ordinary forms of black blasting powder are readily analyzed by the usual methods.

The examination of black blasting powder has been greatly facilitated and, at the same time, made considerably more accurate, by means of a densimeter devised at this laboratory. In this apparatus a Torricellian vacuum is used as a means of displacing the air surrounding the grains of powder, and through very simple manipulation the true density of black powder is determined with a high degree of accuracy. In Building No. 17 there is an apparatus for separating or grading the sizes of black powder.

By means of two factors, the moisture coefficient and the hygroscopic coefficient, which have been worked out at this laboratory, a number of important observations can be made on black powder, in determining the relative efficiency of the graphite coating to resist moisture, and also as a means of judging the thoroughness with which the components of the powder are mixed. The moisture coefficient relates to the amount of moisture which is taken up by the grains of the powder in a definite time under standard conditions of saturation; and the hygroscopic coefficient relates to the affinity of the constituents of the powder for moisture under the same standard conditions.

Besides the examination of explosives used at the testing station, those for the Reclamation Service, the Isthmian Canal Commission, and other divisions of the Government, are also inspected and analyzed at the explosives laboratory. At the present time, the Isthmian Canal Commission is probably the largest user of explosives in the world, and samples used in its work are inspected, tested, and analyzed at this laboratory, and at the branch laboratories at Gibbstown and Pompton Lakes, N. J., and at Xenia, Ohio.

Aside from the usual analysis of explosives for the Isthmian

Canal Commission, special tests are made to determine the liability of the explosive to exude nitro-glycerine, and to deteriorate in unfavorable weather conditions. These tests are necessary, because of the warm and moist climate of the Isthmus of Panama.

Gas and Dust Gallery No. 1.—Gallery No. 1 is cylindrical in form, 100 ft. long, and has a minimum internal diameter of 6⅓ ft. It consists of fifteen similar sections, each 6⅔ ft. long and built up in in-and-out courses. The first three sections, those nearest the concrete head, are of ½-in. boiler-plate steel, the remaining twelve sections are of ⅜-in. boiler-plate steel, and have a tensile strength of, at least, 55 000 lb. per sq. in. Each section has one release pressure door, centrally placed on top, equipped with a rubber bumper to prevent its destruction when opened quickly. In use, this door may be either closed and unfastened, closed and fastened by stud-bolts, or left open. Each section is also equipped with one ¾-in. plate-glass window, 6 by 6 in., centrally placed in the side of the gallery (Fig. 1, and Figs. 1 and 2, Plate XLIX). The sections are held together by a lap-joint. At each lap-joint there is, on the interior of the gallery, a 2½-in., circular, angle iron, on the face of which a paper diaphragm may be placed and held in position by semicircular washers, studs, and wedges. These paper diaphragms are used to assist in confining a gas-and-air mixture.

Natural gas from the mains of the City of Pittsburg is used to represent that found in the mines by actual analysis. A typical analysis of this gas is as follows:

Volumetric Analysis of Typical Natural Gas.

Hydrocarbon vapors	3.1
Carbon dioxide	0
Oxygen	1.2
Heavy hydrocarbons	0.1
Carbon monoxide	0
Methane	69.6
Ethane	13.9
Nitrogen	12.1

The volume of gas used is measured by accurate test meter reading to one-twentieth of a cubic foot. The required amount is admitted near the bottom, to one or more of the 20-ft. divisions of the gallery,

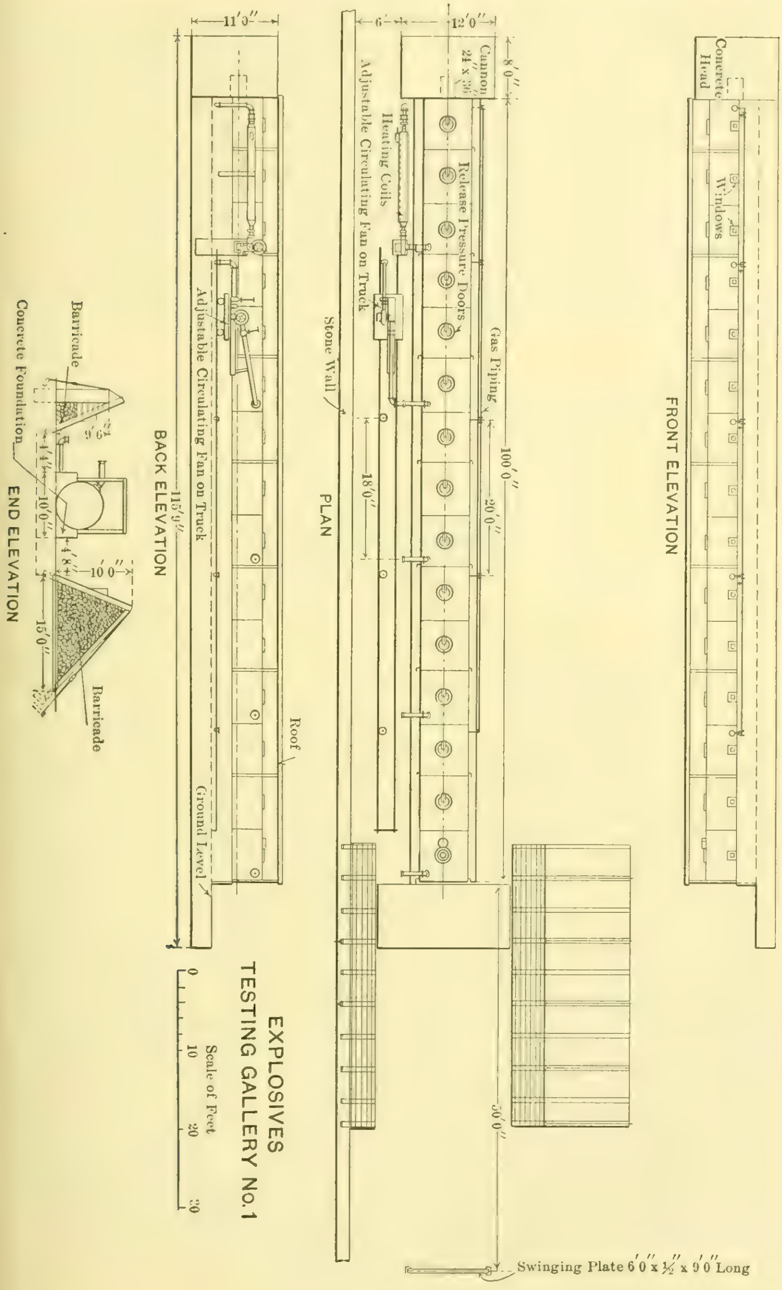

EXPLOSIVES
TESTING GALLERY No.1
Scale of Feet
FRONT ELEVATION
Concrete Head
Windows
PLAN
Cannon 24" x 36"
Release Pressure Doors
Gas Piping
Heating Coils
Adjustable Circulating Fan on Truck
Stone Wall
Swinging Plate 6'0" x ½" x 9'0" Long
BACK ELEVATION
Roof
Ground Level
END ELEVATION
Barricade
Concrete Foundation

FIG. 1.

from a 2-in. pipe, 14 ft. long. The pipe has perforations arranged so that an equal flow of gas is maintained from each unit length.

Each 20-ft. division of the gallery is further equipped with an exterior circulating system, as shown by Fig. 1, thus providing an efficient method of mixing the gas with the air. For the first division this circulating system is stationary, a portion of the piping being equipped with heating coils for maintaining a constant temperature.

The other divisions have a common circulating system mounted on a truck which may be used on any of these divisions. Valves are provided for isolating the fan so that a possible explosion will not injure it.

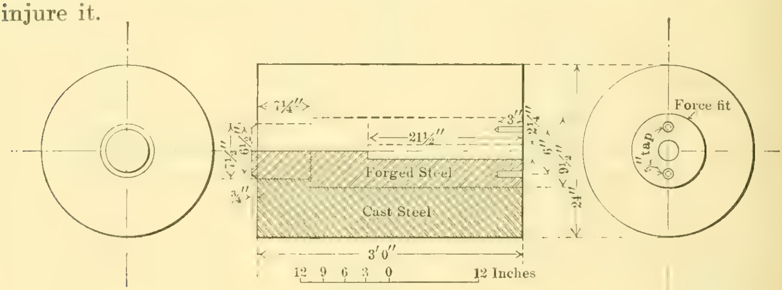


Fig. 2.

In the center section of each division is an indicator cock which is used to provide means of recording pressures above and below atmospheric, or of sampling the air-and-gas mixture. The first division of the gallery is equipped with shelves laterally placed, for the support of coal dust.

The cannon in which the explosive is fired is placed in the concrete head, the axial line of the bore-hole being coincident with that of the gallery. This cannon (Fig. 2) is similar to that used in the ballistic pendulum. The charge is fired electrically from the observation room. To minimize the risk of loading the cannon, the charger carries in his pocket the plug of a stage switch (the only plug of its kind on the ground), so that it is impossible to complete the circuit until the charger has left the gallery. That portion of the first division of the gallery which is not embedded in concrete, has a 3-in. covering made up of blocks of magnesia, asbestos fiber, asbestos, cement, a thin layer of 8-oz. duck, and strips of water-proof roofing paper, the whole being covered with a thick coat of graphite paint. The object of this covering is to assist in maintaining a constant temperature.

The entire gallery rests on a concrete foundation 10 ft. wide, which has a maximum height of 4½ ft. and a minimum height of 2 ft.

The concrete head in which the cannon is placed completely closes that end of the gallery. A narrow drain extends under the entire length of the gallery, and a tapped hole at the bottom of each section provides an efficient means of drainage.

The buildings near the gallery are protected by two barricades near the open end, each 10 ft. high and 30 ft. long. A back-stop, consisting of a swinging steel plate, 6 ft. high and 9 ft. long, 50 ft. from the end of the gallery, prevents any of the stemming from doing damage.

Tests are witnessed from an observation room, a protected position about 60 ft. from the gallery. The walls of the room are 18 in. thick, and the line of vision passes through a ½-in. plate glass, 6 in. wide and 37 ft. long, and is further confined by two external guards, each 37 ft. long and 3 ft. wide.

In this gallery a series of experiments has been undertaken to determine the amount of moisture necessary with different coal dusts, in order to reduce the likelihood of a coal-dust explosion from a blown-out shot of one of the dangerous types of explosives.

Coal dust taken from the roads of one of the coal mines in the Pittsburg district required at least 12% of water to prevent an ignition. It has also been proven that the finer the dust the more water is required, and when it was 100-mesh fine, 30% of water was required to prevent its ignition by the flame of a blown-out shot in direct contact. The methods now used in sprinkling have been proven entirely insufficient for thoroughly moistening the dust, and hence are unreliable in preventing a general dust explosion.

At this station successful experiments have been carried out by using humidifiers to moisten the atmosphere after the temperature of the air outside the gallery has been raised to mine temperature and drawn through the humidifiers. It has been found that if a relative humidity of 90%, at a temperature of 60° Fahr., is maintained for 48 hours, simulating summer conditions in a mine, the absorption of moisture by the dust and the blanketing effect of the humid air prevent the general ignition of the dust.

These humidity tests have been run in Gas and Dust Gallery No. 1 with special equipment consisting of a Koerting exhauster having a

capacity of 240 000 cu. ft. per hour, which draws the air out of the gallery through the first doorway, or that next the concrete head in which the cannon is embedded.

The other end of the gallery is closed by means of brattice cloth and paper diaphragms, the entire gallery being made practically air-tight. The air enters the fifteenth doorway through a box, passing over steam radiators to increase its temperature, and then through the humidifier heads.

Explosives Testing Apparatus.

There is no exposed woodwork in Building No. 17, which is 40 by 60 ft., two stories high, and substantially constructed of heavy stone masonry, with a slate roof. The structure within is entirely fire-proof. Iron columns and girders, and wooden girders heavily encased in cement, support the floors which are either of cement slab construction or of wooden flooring protected by expanded metal and cement both above and beneath. At one end, on the ground floor, is the exposing and recording apparatus for flame tests of explosives, also pressure gauges, and a calorimeter, and, at the other end, is a gallery for testing safety lamps.

The larger portion of the second floor is occupied by a gas-tight training room for rescue work, and an audience chamber, from which persons interested in such work may observe the methods of procedure. A storage room for rescue apparatus and different models of safety lamps is also on this floor.

The disruptive force of explosives is determined in three ways, namely, by the ballistic pendulum, by the Bichel pressure gauge, and by Trauzl lead blocks.

Ballistic Pendulum.—The disruptive force of explosives, as tested by the ballistic pendulum, is measured by the amount of oscillation. The standard unit of comparison is a charge of ½ lb. of 40% nitro-glycerine dynamite. The apparatus consists essentially of a 12-in. mortar (Fig. 3, Plate XLIX), weighing 31 600 lb., and suspended as a pendulum from a beam having knife-edges. A steel cannon is mounted on a truck set on a track laid in line with the direction of the swing of the mortar. At the time of firing the cannon may be placed $\frac{1}{16}$-in. from the muzzle of the mortar. The beam, from which the mortar is suspended, rests on concrete walls, 51 by 120 in. at the

base and 139 in. high. On top of each wall is a 1-in. base-plate, 7 by 48 in., anchored to the wall by $\frac{5}{8}$-in. bolts, 28 in. long. The knife-edges rest on bearing-plates placed on these base-plates. The bearing-plates are provided with small grooves for the purpose of keeping the knife-edges in oil and protected from the weather. The knife-edges are each 6 in. long, $2\frac{11}{16}$ in. deep from point to back, 2 in. wide at the back, and taper 50° with the horizontal, starting on a line $1\frac{1}{2}$ in. from the back. The point is rounded to conform to a radius of $\frac{1}{4}$ in. The back of each is 2 in. longer than the edge, making a total length of 10 in., and is 1 in. deep and 12 in. wide. This shoulder gives bolting surface to the beam from which the mortar is hung. The beam is of solid steel, has a 4 by 8-in. section, and is 87 in. long. Heavy steel castings are bolted to it to take the threads of the machine-steel rods which form the saddles on which the mortar is suspended. The radius of the swing, measured from the point of the knife-edges to the center of the trunnions, is $89\frac{3}{4}$ in.

The cannon consists of two parts, a jacket and a liner. The jacket is 36 in. long, has an external diameter of 24 in., and internal diameters of $9\frac{1}{2}$ and $7\frac{1}{2}$ in. It is made of the best cast steel or of Vanadium steel.

The liner is $36\frac{1}{2}$ in. long, with a 1-in. shoulder, $7\frac{3}{4}$ in. from the back, changing the diameter from $9\frac{1}{2}$ to $7\frac{1}{2}$ in. The bore is smooth, being $2\frac{1}{4}$ in. in diameter and $21\frac{1}{2}$ in. long. The cannon rests on a 4-wheel truck, to which it is well braced by straps and rods. A track of 30-in. gauge extends about 9 ft. from the muzzle of the mortar to the bumper for the cannon.

The shot is fired by an electric firing battery, from the first floor of Building No. 17, about 10 yd. away. To insure the safety of the operator and the charger, the man who loads the cannon carries a safety plug without which the charge cannot be exploded. The wires for connecting to the fuse after charging are placed conveniently, and the safety plug is then inserted in a box at the end of the west wall. The completion of the firing battery by the switch at the firing place is indicated by the flashing of a red light, after which all that is necessary to set off the charge is to press a button on the battery. An automatic recording device at the back of the mortar records the length of swing which, by a vernier, may be read to $\frac{1}{200}$ in.

Bichel Pressure Gauges.—Pressure gauges are constructed for the purpose of determining the unit disruptive force of explosives detonat-

ing at different rates of velocity, by measuring pressures developed in an enclosed space from which the generated gases cannot escape. The apparatus consists of a stout steel cylinder, which may be made absolutely air-tight; an air-pump and proper connections for exhausting the air in the cylinder to a pressure equivalent to 10 mm. of mercury; an insulated plug for providing the means of igniting the charge; a valve by which the gaseous products of combustion may be removed for subsequent analysis; and an indicator drum (Fig. 1, Plate L) with proper connections for driving it at a determinable speed.

This apparatus is in the southeast corner of Building No. 17. The cylinder is 31½ in. long, 19¾ in. in diameter, and is anchored to a solid concrete footing at a convenient height for handling. The explosion chamber is 19 in. long and 7⅞ in. in diameter, with a capacity of exactly 15 liters. The cover of the cylinder is a heavy piece of steel held in place by stout screw-bolts and a heavy steel clamp.

The charge is placed on a small wire tripod, and connections are made with a fuse to an electric firing battery for igniting the charges. The cover is drawn tight, with the twelve heavy bolts against lead washers. The air in the cylinder is exhausted to 10 mm., mercury column, in order to approach more closely the conditions of a stemmed charge exploding in a bore-hole inaccessible to air; the indicator drum is placed in position and set in motion; and, finally, the shot is fired. The record shown on the indicator card is a rapidly ascending curve for quick explosives and a shallower, slowly rising curve for explosives of slow detonation. When the gases cool, the curve merges into a straight line, which indicates the pressures of the cooled gases on the sides of the chamber.

Since the ratio of the volume of the cylinder to the volume of the charge may be computed, the pressure of the confined charge may also be found, and this pressure often exceeds 100 000 lb. per sq. in. The cooling effect of the inner surface on the gaseous products of combustion, a vital point in computations of the disruptive force of explosives by this method, is determined by comparing the pressures obtained in the original cylinder with those in a second cylinder of larger capacity, into which has been inserted one or more steel cylinders to increase the superficial area while keeping the volume equal to that of the first cylinders. By comparing results, a curve may be plotted, which will

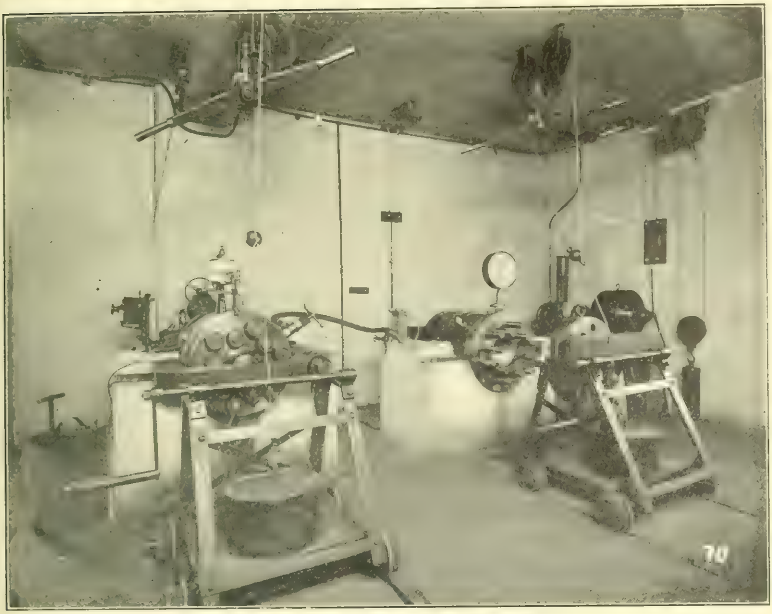


FIG. 1.—BICHEL PRESSURE GAUGES.

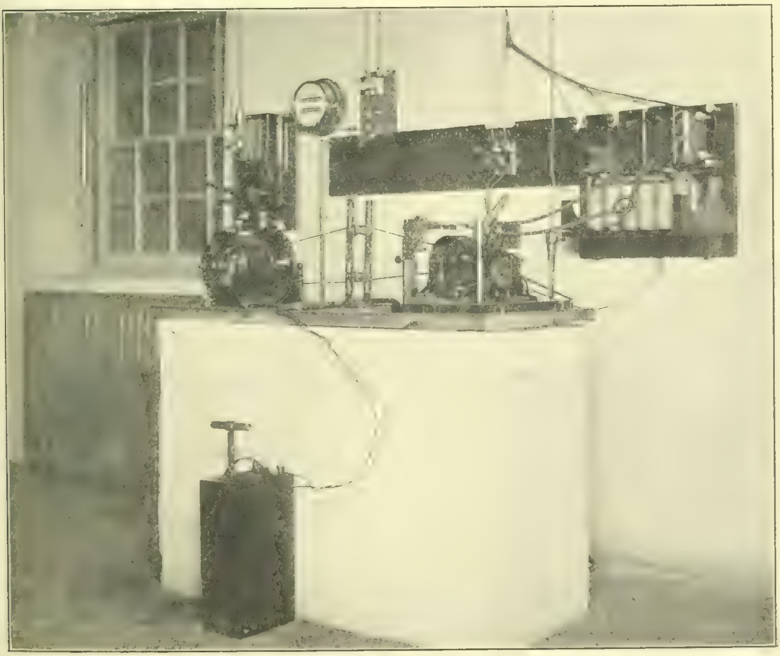


FIG. 2.—RATE OF DETONATION RECORDER.

determine the actual pressures developed with the surface-cooling effect eliminated.

Trauzl Lead Blocks.—The lead-block test is the method adopted by the Fifth International Congress of Applied Chemistry as the standard for measuring the disruptive force of explosives. The unit by this test is defined to be the force required to enlarge the bore-hole in the block to an amount equivalent to that produced by 10 grammes of standard 40% nitro-glycerine dynamite stemmed with 50 grammes of dry sand under standard conditions as produced with the tamping device. The results of this test, when compared with those of the Bichel gauge, indicate that, for explosives of high detonation, the lead block is quite accurate, but for slow explosives, such as gunpowder, the expansion of the gases is not fast enough to make comparative results of value. The reason for this is that the gases escape through the bore of the block rather than take effect in expanding the bore-hole.

The lead blocks are cylindrical, 200 mm. in diameter, and 200 mm. high. Each has a central cavity, 25 mm. in diameter and 125 mm. deep (Fig. 1, Plate LII), in which the charge is placed. The blocks are made of desilverized lead of the best quality, and, as nearly as possible, under identical conditions. The charge is placed in the cavity and prepared for detonation with an electrical exploder and stemming. After the explosion the bore-hole is pear-shaped, the size of the cavity depending, not only on the disruptive power of the explosive, but also on its rate of detonation, as already indicated. The size of the bore-hole is measured by filling the cavity with water from a burette. The difference in the capacity of the cavity before and after detonation indicates the enlarging power of the explosive.

Calorimeter.—The explosion calorimeter is designed to measure the amount of heat given off by the detonation of explosive charges of 100 grammes. The apparatus consists of the calorimeter bomb (Fig. 1, Plate LI), the inner receiver or immersion vessel, a wooden tub, a registering thermometer, and a hocking frame. This piece of apparatus stands on the east side of Building No. 17.

The bottle-shaped bomb is made of ½-in. wrought steel, and has a capacity of 30 liters. On opposite sides near the top are bored apertures, one for the exhaust valve for obtaining a partial vacuum (about 20 mm., mercury column) after the bomb has been charged, the other for inserting the plug through which passes the fuse wire for igniting

the charge. The bomb is closed with a cap, by which the chamber may be made absolutely air-tight. It is 30 in. high with the cap on, weighs 158 lb., and is handled to and from the immersion vessel by a small crane.

The inner receiver is made of $\frac{1}{16}$-in. sheet copper, 30⅝ in. deep, and with an inner diameter of 17⅝ in. It is nickel-plated and strengthened on the outside with bands of copper wire, and its capacity is about 70 liters. The outer tub is made of 1-in. lumber strengthened with four brass hoops on the outside. It is 33 in. deep, and its inner diameter is 21 in.

The stirring device, operated vertically by an electric motor, consists of a small wooden beam connected to a system of three rings having a horizontal bearing surface. When the apparatus is put together, the inner receiver rests on a small standard on top of the base of the outer tank, and the rings of the stirring device are run between the bomb and the inner receiver. The bomb itself rests on a small standard placed on the bottom of the inner receiver. The apparatus is provided with a snugly fitting board cover. The bomb is charged from the top, the explosive being suspended in its center. The air is exhausted to the desired degree of rarification. The caps are then screwed on, and the apparatus is set together as described.

The apparatus is assembled on scales and weighed before the water is poured in and after the receiver is filled. From the weight of the water thus obtained and the rise of temperature, the calorific value may be computed. The charge is exploded by electricity, while the water is being stirred. The rise in the temperature of the water is read by a magnifying glass, from a thermometer which measures temperature differences of 0.01 degrees. From the readings obtained, the maximum temperature of explosion may be determined, according to certain formulas for calorimetric experiments. Proper corrections are made for the effects, on the temperature readings, of the formation of the products of combustion, and for the heat-absorbing power of the apparatus.

Impact Machine.—In Building No. 17, at the south side, is an impact machine designed to gauge the sensitiveness of explosives to shock. For this purpose, a drop-hammer, constructed to meet the following requirements, is used: A substantial, unyielding foundation; minimum friction in the guide-grooves; and no escape or scattering

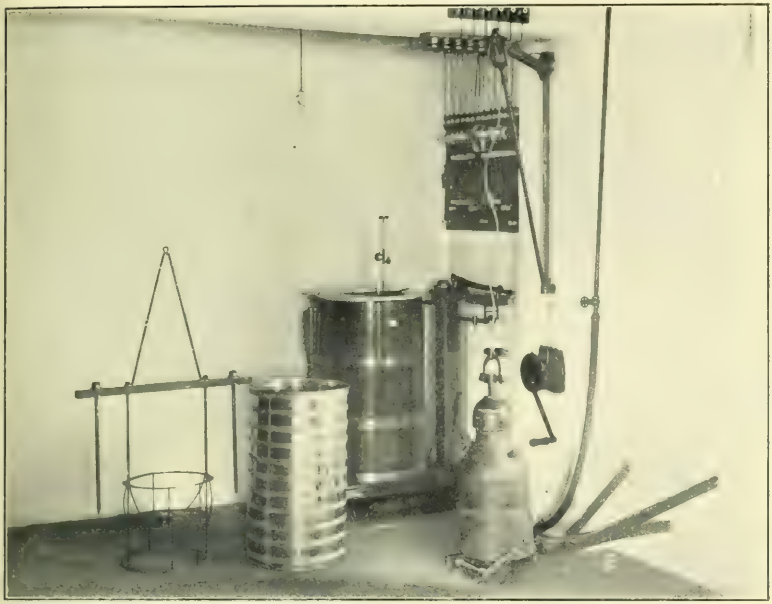


FIG. 1.—EXPLOSIVES CALORIMETER.

FIG. 2. BUILDING NO. 17. AND FLAME TEST APPARATUS.

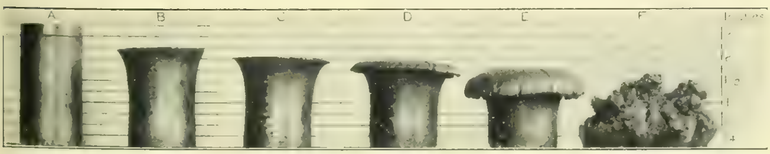


FIG. 3.—SMALL LEAD BLOCK TEST.

of the explosive when struck by the falling weight. This machine is modeled after one used in Germany, but is much improved in details of construction.

The apparatus, Fig. 1, Plate LIV, consists essentially of the following parts: An endless chain working in a vertical path and provided with lugs; a steel anvil on which the charge of explosive is held by a steel stamp; a demagnetizing collar moving freely in vertical guides and provided with jaws placed so that the lugs of the chain may engage them; a steel weight sliding loosely in vertical guides and drawn by the demagnetizing collar to determinable heights when the machine is in operation; a second demagnetizing collar, which may be set at known heights, and provided with a release for the jaws of the first collar; and a recording device geared to a vertically-driven threaded rod which raises or lowers, sets the second demagnetizing collar, and thus determines the height of fall of the weight. By this apparatus the weight may be lifted to different known heights, and dropped on the steel stamp which transmits the shock to the explosive. The fall necessary to explode the sample is thus determined.

The hammers are of varying weight, the one generally used weighing 2 000 grammes. As the sensitiveness of an explosive is influenced by temperature changes, water at 25° cent. is allowed to flow through the anvil in order to keep its temperature uniform.

Flame Test.—An apparatus, Fig. 2, Plate LI, designed to measure the length and duration of flames given off by explosives, is placed at the northeast corner of Building No. 17. It consists essentially of a cannon, a photographing device, and a drum geared for high speed, to which a sensitized film may be attached.

About 13 ft. outside the wall of Building No. 17, set in a concrete footing, is a cannon pointing vertically into an encasing cylinder or stack, 20 ft. high and 43 in. in diameter. This cannon is a duplicate of the one used for the ballistic pendulum, details of which have already been given. The stack or cylinder is of ¼-in. boiler plate, in twenty-four sections, and is absolutely tight against light at the base and on the sides. It is connected with a dark room in Building No. 17 by a light-tight conduit of rectangular section, 12 in. wide, horizontal on the bottom, and sloping on the top from a height of 8½ ft. at the stack to 21 in. at the inside of the wall of the building.

The conduit is carefully insulated from the light at all joints, and

is riveted to the stack. A vertical slit, 2 in. wide and 8 ft. long, coincident with the center line of the conduit, is cut in the stack. A vertical plane drawn through the center line of the bore-hole of the cannon and that of the slit, if produced, intersects the center line of a quartz lens, and coincides with the center of a stenopaic slit and the axis of the revolving drum carrying the film. The photographing apparatus consists of a shutter, a quartz lens, and a stenopaic slit, 76 by 1.7 mm., between the lens and the sensitized film on the rotary drum. The quartz lens is used because it will focus the ultra-violet rays, which are those attending extreme heat.

The drum is 50 cm. in circumference and 10 cm. deep. It is driven by a 220-volt motor connected to a tachometer which reads both meters per second and revolutions per minute. A maximum peripheral speed of 20 m. per sec. may be obtained.

When the cannon is charged, the operator retires to the dark room in which the recording apparatus is located, starts the drum, obtains the desired speed, and fires the shot by means of a battery. When developed, the film shows a blur of certain dimensions, produced by the flame from the charge. From the two dimensions—height and lateral displacement—the length and duration of the flame of the explosive are determined.

The results of flame tests of a permissible explosive and a test of black blasting powder, all shot without stemming, are shown on Fig. 2, Plate LII. In this test, the speed of the drum carrying the black powder negative was reduced to one sixty-fourth of that for the permissible explosives, in order that the photograph might come within the limits of the negative. In other words, the duration of the black powder flame, as shown, should be multiplied by 64 for comparison with that of the permissible explosive, which is from 3 500 to 4 000 times quicker.

Apparatus for Measuring Rate of Detonation.—The rate at which detonation travels through a given length of an explosive can be measured by an apparatus installed in and near Building No. 17. Its most essential feature is a recording device, with an electrical connection, by which very small time intervals can be measured with great exactness.

The explosive is placed in a sheet-iron tube about 1½ in. in diameter and 4 ft. long, and suspended by cords in a pit, 11 ft. deep and 16 ft. in diameter. This pit was once used as the well of a gas tank,

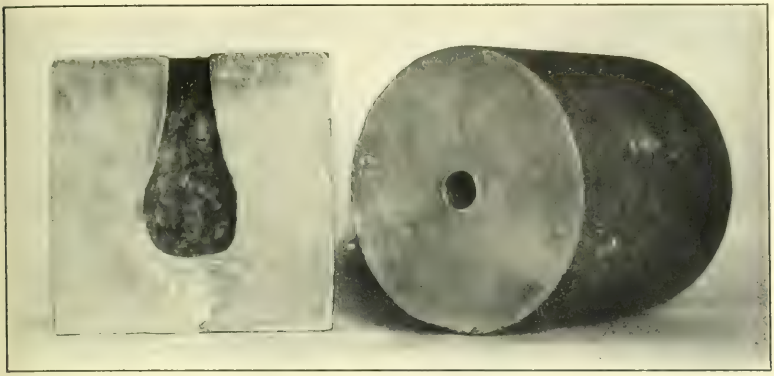


FIG. 1.—TRAUZL LEAD BLOCKS.

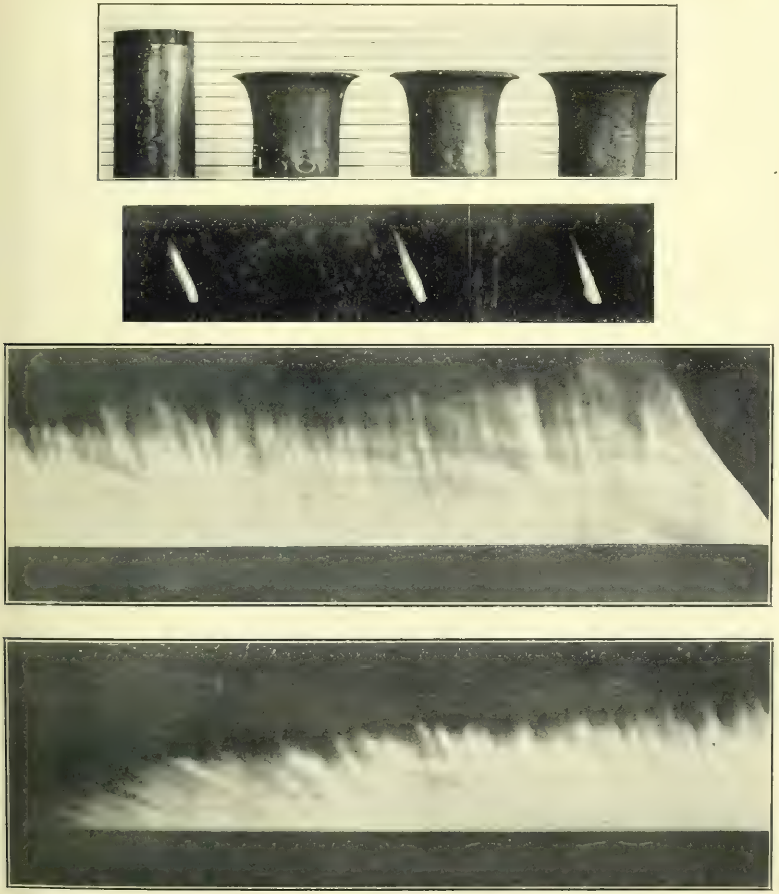


FIG. 2.—POWDER FLAMES.

Fig. 2, Plate LI. In adapting the pit to its new use, the tank was cut in two; the top half, inverted, was placed in the pit on a bed of saw-dust, and the space between the tank and the masonry walls of the pit was filled with saw-dust. The cover of the pit consists of heavy timbers framed together and overlaid by a 12-in. layer of concrete reinforced by six I-beams. Four straps extend over the top and down to eight "dead men" planted about 8 ft. below the surface of the ground.

The recording device, known as the Mettegang recorder, Fig. 2, Plate L, comprises two sparking induction coils and a rapidly revolving metallic drum driven by a small motor, the periphery of the drum having a thin coating of lampblack. A vibration tachometer which will indicate any speed between 50 and 150 rev. per sec., is directly connected to the drum, so that any chance of error by slipping is eliminated. The wires leading to the primary coils of the sparking coils pass through the explosive a meter or more apart. Wires lead from the secondary coils to two platinum points placed a fraction of a millimeter from the periphery of the drum. A separate circuit is provided for the firing lines.

In making a test, the separate cartridges, with the paper trimmed from the ends, are placed, end to end, in the sheet-iron tube; the drum is given the desired peripheral speed, and the charge is exploded. The usual length between the points in the tube is 1 m., and the time required for the detonation of a charge of that length is shown by the distance between the beginning of two rows of dots on the drum made by the sparks from the secondary coil circuits, the dots starting the instant the primary circuits are broken by the detonation. At one end of the drum are gear teeth, 1 mm. apart on centers, which can be made to engage a worm revolving a pointer in front of a dial graduated to hundredths; by means of this and a filar eyepiece, the distance between the start of the two rows of spark dots on the drum can be measured accurately to 0.01 mm. As the drum is 500 mm. in circumference, and its normal speed is 86 rev. per sec., it is theoretically possible to measure time to one four-millionth of a second, though with a cartridge 1 m. long, such refinement has not been found necessary.

The use of small lead blocks affords another means of determining the rate of detonation or quickness of an explosive. Each block (a cylinder, 2½ in. long and 1½ in. in diameter) is enclosed in a piece of

paper so that a shell is formed above the block, in which to place the charge. A small steel disk of the same diameter as the block is first placed in the shell on top of the block, then the charge with a detonator is inserted. The charge is customarily 100 grammes. On detonation of the charge, a deformation of the lead takes place, the amount of which is due to the quickness of the explosive used (Fig. 3, Plate LI).

Sample Record of Tests.

The procedure followed in the examination of an explosive is shown by the following outline:

1.—Physical Examination.

(*a*).—Record of appearance and marks on original package.

(*b*).—Dimensions of cartridge.

(*c*).—Weight of cartridge, color and specific gravity of powder.

2.—Chemical Analysis.

(*a*).—Record of moisture, nitro-glycerine, sodium or potassium nitrate, and other chemical constituents, as set forth by the analysis; percentage of ash, hygroscopic coefficient—the amount of water taken up in 24 hours in a saturated atmosphere, at 15° cent., by 5 grammes, as compared with the weight of the explosive.

(*b*).—Analysis of products of combustion from 100 grammes, including gaseous products, solids, and water.

(*c*).—Composition of gaseous products of combustion, including carbon monoxide and carbon dioxide, hydrogen, nitrogen, etc.

(*d*).—Composition of solid products of combustion, subdivided into soluble and insoluble.

3.—A Typical Analysis of Natural Gas.

Used in tests, as follows:

Carbon dioxide	0.0 per cent.
Heavy hydrocarbons	0.2 " "
Oxygen	0.1 " "
Carbon monoxide	0.0 " "
Methane	82.4 " "
Ethane	15.3 " "
Nitrogen	2.0 " "
	100.00 per cent.

4.—Typical Analysis of Bituminous Coal Dust, 100-Mesh Fine, Used in Tests.

Moisture	1.90
Volatile matter	35.05
Fixed carbon	58.92
Ash	4.13
	100.00
Sulphur	1.04

5.—An Average Analysis of Detonators.

Used on Trauzl lead blocks, pressure gauge, calorimeter, and small lead blocks:

$M - l \frac{l}{m}$. Triple-strength exploder.

Charge ....1.5729 grammes.

	Mercury fulminate.	Chlorate of potash.
Specification	89.73	10.27

Used on all other tests:

$M - 260 \frac{l}{m}$. Double-strength exploder.

Charge ....0.9805 grammes.

	Mercury fulminate.	Chlorate of potash.
Specification	91.31	8.69

6.—Ballistic-Pendulum Tests.

This record includes powder used, weight of charge, swing of mortar, and unit disruptive charge, the latter being the charge required to produce a swing of the mortar equal to that produced by ½ lb. (227 grammes) of 40% dynamite, or 3.01 in.

7.—Record of Tests.

Tests Nos. 1 to 5 in Gallery No. 1, as set forth in preceding circular.

8.—Trauzl Lead-Block Test.

Powder and test numbers, expansion of bore-hole in cubic centimeters, and average expansion compared with that produced by a like quantity (10 grammes) of 40% dynamite, the latter giving an average expansion of 294 cu. cm.

9.—Pressure Gauge.

Powder and test number, weight of charge, charging density, height of curve, pressure developed, and pressure developed after cooling, com-

pared with pressure developed after elimination of surface influences by a like quantity (100 grammes) of 40% dynamite, the average being 8 439 kg. per sq. cm.

10.—Rate of Detonation.

Powder and test number, size of cartridge, and rate of detonation in meters per second, for comparison with rate of detonation of 40% dynamite, which, under the same conditions, averages 4 690 m. per sec.

11.—Impact Machine.

Explosive and test numbers, distance of fall (2 000-gramme weight) necessary to cause explosion, for comparison with length of fall, 11 cm., necessary to cause explosion of 40% dynamite.

12.—Distance of Explosive Wave Transmitted by 1.25 by 8-in. Cartridge.

Explosive and test numbers, weight of cartridge, distance separating cartridges in tests, resulting explosion or non-explosion, for comparison with two cartridges of 40% dynamite, hung, under identical conditions, 13 in. apart, end to end, in which case detonation of the first cartridge will explode the second.

13.—Flame Test.

Explosive and test numbers, charge 100 grammes with 1 lb. of clay stemming, average length of flame and average duration of flame, for comparison with photographs produced by 40% dynamite under like conditions.

14.—Small Lead Blocks.

Powder and test numbers, weight of charge, and compression produced in blocks.

15.—Calories Developed.

Number of large calories developed per kilogramme of explosive, for comparison with 1 000 grammes of 40% dynamite, which develop, on an average, 1 229 large calories.

Blasting Powder Separator.

The grains of black blasting powder are graded by a separator, similar to those used in powder mills, but of reduced size. It consists of an inclined wooden box, with slots on the sides to carry a series of screens, and a vertical conduit at the end for carrying off the grains as they are screened into separate small bins (Fig. 1, Plate LIII). At the upper end of the screens is a small 12 by 16-in. hopper, with a sliding brass apron to regulate the feed. The screens are shaken

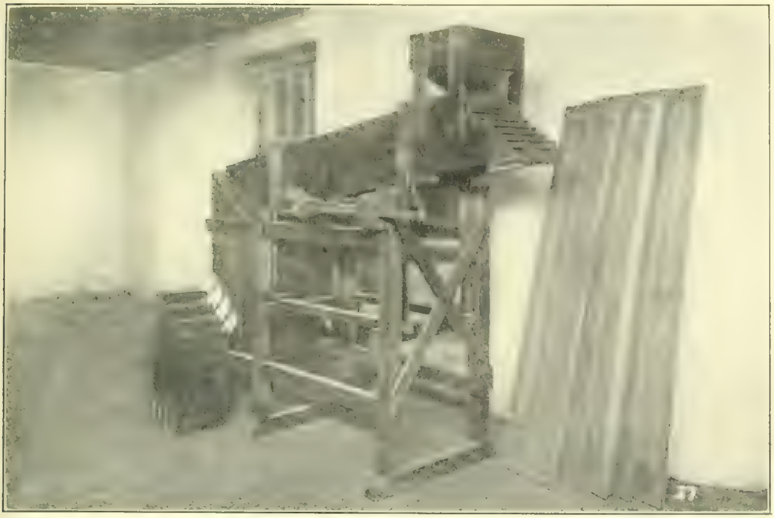


FIG. 1. SEPARATOR FOR GRADING BLACK POWDER.

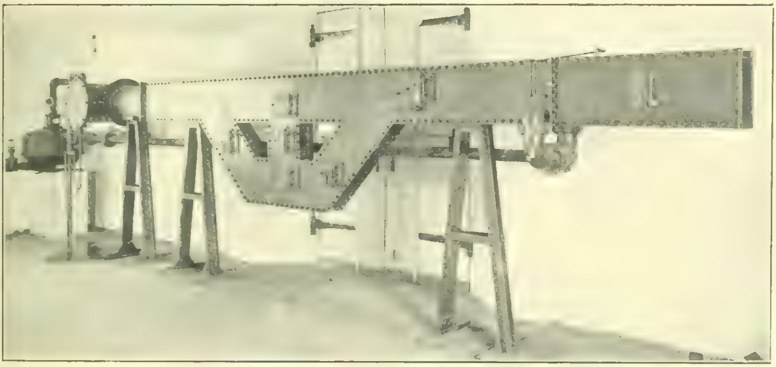


FIG. 2.—SAFETY LAMP TESTING GALLERY.

FIG. 3.—MINE GALLERY NO. 2.

laterally by an eccentric rod operated by hand. The top of the hopper is about $6\frac{1}{2}$ ft. above the floor. The box is 6 ft. 10 in. long, from tip to tip, and inclines at an angle of 9 degrees.

After separation the grains fall through a vertical conduit, and thence to the bins through zinc chutes, 1 by 2 in. in section. Care is taken to have no steel or iron exposed to the powder.

The screens are held by light wooden frames which slip into the inclined box from the upper end. In this way, any or all of the screens may be used at once, thus separating all grades, or making only such separations as are desired. The screens with the largest meshes are diagonally perforated zinc plates. Table 2 gives the number of holes per square foot in zinc plates perforated with circular holes of the diameters stated.

TABLE 2.—NUMBER OF HOLES PER SQUARE FOOT IN ZINC PLATES WITH CIRCULAR PERFORATIONS.

Diameter, in inches.	Number of holes.	Diameter, in inches.	Number of holes.	Diameter, in inches.	Number of holes.	Diameter, in inches.	Number of holes.
$\frac{1}{2}$	353	$\frac{1}{3}$	782	$\frac{1}{5}$	1 680	$\frac{1}{10}$	6 636
$\frac{4}{10}$	518	$\frac{1}{4}$	1 392	$\frac{1}{8}$	3 456	$\frac{1}{16}$	12 800

The finer meshes are obtained by using linen screens with holes of two sizes, namely, $\frac{1}{20}$ in. square and $\frac{1}{28}$ in. square.

Until a few years ago, black blasting powder was manufactured in the sizes given in Table 3.

TABLE 3.—GRADATION OF BLACK BLASTING POWDER.

Grade.	Mesh.	Grade.	Mesh.
CC	2–$2\frac{1}{2}$	FF	5–8
C	$2\frac{1}{2}$–3	FFF	8–16
F	3–5	FFFF	16–28

In late years there has been considerable demand for special sizes and mixed grains for individual mines, especially in Illinois. As no material change has been made in the brands, the letters now used are not indicative of the size of the grains, which they are supposed to represent. Of 29 samples of black blasting powder recently received

from the Illinois Powder Commission, only 10 were found to contain 95% of the size of grains they were supposed to represent; 4 contained 90%; 7 varied from 80 to 90%; several others were mixtures of small and large grains, and were branded FF black blasting powder; and one sample contained only 8.5% of the size of grains it was supposed to represent. The remaining samples showed many variations, even when sold under the same name. The practice of thus mixing grades is exceedingly dangerous, because a miner, after becoming accustomed to one brand of FF powder of uniform separation, may receive another make of similar brand but of mixed grains, and, consequently, he cannot gauge the quantity of powder to be used. The result is often an over-load or a blown-out shot. The smaller grains will burn first, and the larger ones may be thrown out before combustion is complete.

Lamp Testing Gallery.

At the Pittsburg testing station, there is a gallery for testing safety lamps in the presence of various percentages of inflammable gas. In this gallery the safety of the lamps in these gaseous mixtures may be tested, and it is also possible for mine inspectors and fire bosses to bring their safety lamps to this station, and test their measurements of percentage of gas, by noting the length and the appearance of the flame in the presence of mixtures containing known percentages of methane and air.

The gas-tight gallery used for testing the lamps, consists of a rectangular conduit (Fig. 2, Plate LIII), having sheet-steel sides, 6 mm. thick and 433 mm. wide, the top and bottom being of channel iron. The gallery rests on two steel trestles, and to one end is attached a No. 5 Koerting exhauster, capable of aspirating 50 cu. m. per min., under a pressure of 500 mm. of water, with the necessary valve, steam separator, etc. The mouth of the exhauster passes through the wall of the building and discharges into the open air.

Besides the main horizontal conduit, there are two secondary conduits connected by a short horizontal length, and the whole is put together so that the safety lamp under test may be placed in a current of air, or of air and gas, which strikes it horizontally, vertically upward or downward, or at an angle of 45° (Fig. 3). The path of the current is determined by detachable sheet-steel doors.

There are five double observing windows of plate glass, which open

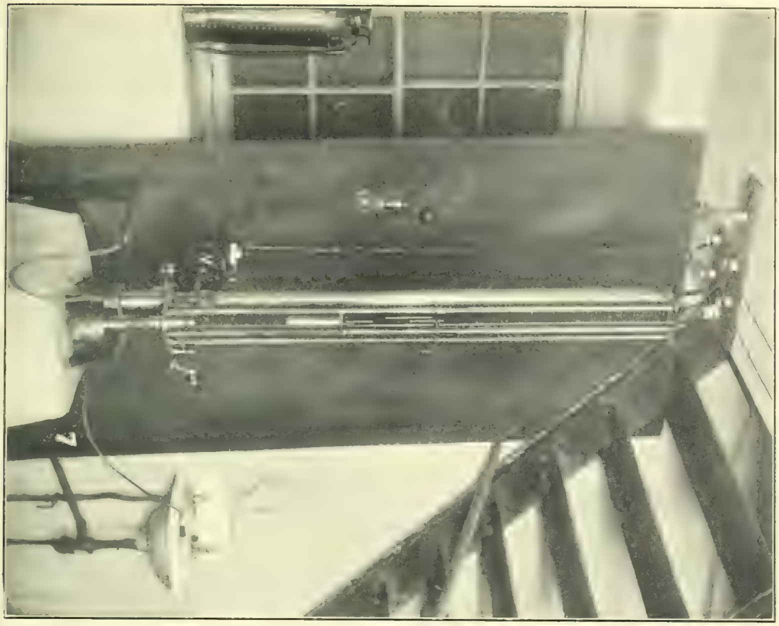


FIG. 1. IMPACT MACHINE.

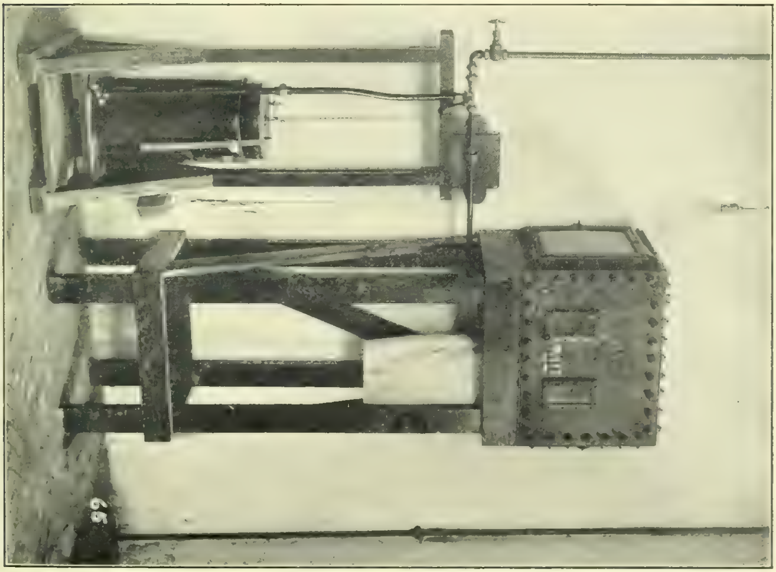


FIG. 2. LAMP TESTING BOX.

on hinges. The size of each window is 7½ by 3 in.; the inner glass is ¼ in. thick and the outer one, ½ in. thick. These glasses are separated by a space of ¼ in. The upper conduit has four safety doors along the top, each of the inclined conduits has one safety door, and the walls and windows are provided with rubber gaskets or asbestos packing, to make them gas-tight. The cross-sectional area of the conduit is 434 sq. cm.

The air inlet consists of 36 perforations, 22 mm. in diameter, in a bronze plate or diaphragm. The object of this diaphragm is to produce pressure in the conduit before the mixing boxes, and permit the measuring of the velocity of the current. The air-current, after passing through the holes, enters the mixer, a cast-steel box traversed by 36 copper tubes, each perforated by 12 openings, 3 mm. in diameter, arranged in a spiral along its length and equally spaced. The total cross-sectional area of the tubes is 137 sq. cm.

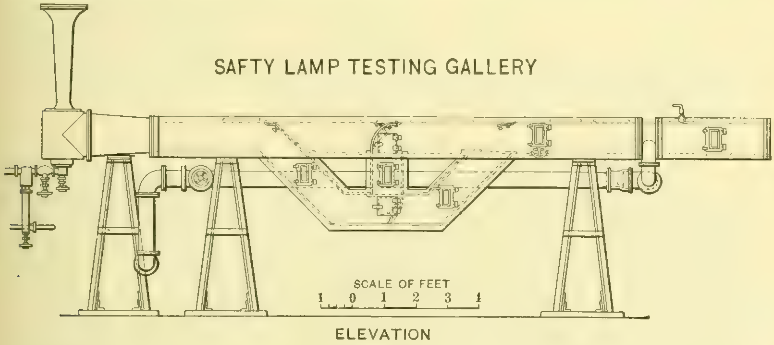


FIG. 3.

The explosive gas enters the interior of the box around the tubes through large pipes, each 90 mm. in diameter, passes thence through the 432 openings in the copper tubes, and mixes thoroughly with the air flowing through these tubes. The current through the apparatus is induced by the exhauster, and its course is determined by the position of the doors.

The gallery can be controlled so as to provide rapidly and easily a current of known velocity and known percentage of methane. In the explosive current of gas and air, safety lamps of any size or design can be tested under conditions simulating those found occasionally in mines, air-currents containing methane in dangerous proportions

striking the lamps at different angles, and the relative safety of the various types of lamps under such conditions can be determined. In this gallery it is also possible to test lighting devices either in a quiet atmosphere or in a moving current, and, by subjecting the lamps to air containing known percentages of methane, it is possible to acquaint the user with the appearance of flame caps.

Breathing Apparatus.

With this apparatus, the wearer may explore a gaseous mine, approach fires for the purpose of fighting them, or make investigations after an explosion. Its object is to provide air or oxygen to be breathed by the wearer in coal mines, when the mine air is so full of poisonous gases as to render life in its presence impossible.

A variety of forms of rescue helmets and apparatus are on the market, almost all of European manufacture, which are being subjected to comparative trials as to their durability and safety, the ease or inconvenience involved in their use, etc. All consist essentially of helmets which fit air-tight about the head, or of air-tight nose clamps and mouthpieces (Fig. 1, Plate LV).

These several forms of breathing apparatus are of three types:

1.—The liquid-air type, in which air, in a liquid state, evaporates and provides a constant supply of fresh air.

2.—The chemical oxygen-producing type, which artificially makes or supplies oxygen for breathing at about the rate required; and,

3.—The compressed-oxygen type.

Apparatus of the first type, weighing 20 lb., supplies enough air to last about 3 hours, and the products of breathing pass through a check-valve directly into space. Apparatus of the second type supplies oxygen obtained from oxygen-producing chemicals, and also provides means of absorbing the carbonic acid gas produced in respiration. They contain also the requisite tubes, valves, connections, etc., for the transmission of the fresh air and the respired air so as to produce sufficient oxygen while in use; to absorb and purify the products of expiration; and to convey the fresh air to the mouth without contamination by the atmosphere in which the apparatus is used. Three oxygen-generating cartridges are provided, each supplying oxygen enough for 1 hour, making the total capacity 3 hours. Changes of cylinders can be made in a few seconds while breathing

FIG. 1.—BREATHING AND RESCUE APPARATUS.

FIG. 2.—RESCUE TRAINING ROOM.

is suspended. This apparatus weighs from 20 to 25 lb., according to the number of oxygen generators carried. The cartridges for generating oxygen, provided with this apparatus, are of no value after having been used for about an hour.

The third type of apparatus is equipped with strong cylinders charged with oxygen under high pressure; two potash regenerative cans for absorbing the carbon dioxide gas exhaled; a facial helmet; the necessary valves, tubes, etc., for the control of the oxygen; and a finimeter which registers the contents of the cylinders in atmospheres and minutes of duration. The two cartridges used for absorbing the carbonic acid gas are of no value after having been in use for two hours.

If inhalation is through the mouth alone, a mouthpiece is attached to the end of the breathing tube by which the air or oxygen is supplied, the nose is closed by a clip, and the eyes are protected by goggles. To inhale through both nose and mouth, the miner wears a helmet or headgear which can be made to fit tightly around the face. The helmet has two tubes attached, one for inspiration and the other for expiration. In the oxygen-cylinder apparatus these tubes lead to and from rubber sacks used for pure-air and bad-air reserves.

Mine-Rescue Training.

It has been found in actual service that when a miner, equipped with breathing apparatus for the first time, enters a mine in which an explosion has occurred, he is soon overcome by excitement or nervousness induced by the artificial conditions of breathing imposed by the apparatus, the darkness and heat, and the consciousness that he is surrounded with poisonous gases. It has also been found that a brief period of training in the use of such apparatus, under conditions simulating those encountered in a mine after a disaster, gives the miner confidence and enables him to use the apparatus successfully under the strain of the vigorous exertion incident to rescue work.

The rescue corps consists of five or six miners under the direction of a mining engineer who is experienced in rescue operations and familar with the conditions existing after mine disasters. The miners work in pairs, so that one may assist the other in case of accident, or of injury to the breathing apparatus, and so that each may watch the

condition of the oxygen supply, as shown by the gauges in the other's outfit.

The training is given in the gas-tight room of Building No. 17, or in similar rooms at sub-stations (Fig. 2, Plate LV). This room is made absolutely dark, and is filled with a noxious mixture of SO_2, CO_2, or of CO, produced by burning sulphur or charcoal on braziers. At each period of training, the miners enter and walk a distance of about 1 mile, the average distance usually traveled from the mine mouth to the working face or point of explosion. They then remove a number of timbers; lift a quantity of brick or hard lump-coal into wheel-barrows; climb through artificial tunnels, up and down inclines, and over surfaces strewn with coal or stone; operate a machine with a device attached to it, which automatically records the foot-pounds of work done; and perform other vigorous exercise, during a period of 2 hours. This routine is repeated daily during 1 week, after which the rescue corps is considered sufficiently trained for active service.

The apparatus used for recording the foot-pounds of work done by the person operating the work machine within the gas-tight rescue room, comprises a small dial with electrical connections, which records the number of strokes made by the machine, and a pencil point which rests on a paper diaphragm, fastened to a horizontal brass disk. This disk is driven by clockwork, and makes one complete revolution per hour. When the machine is in operation, the pencil point works back and forth, making a broad line on the paper; when the operator of the machine rests, the pencil point traces a single line. The apparatus thus records the number of strokes given by the operator during a given time. From the weight lifted, the height of lift, and the number of strokes in the given time, the foot-pounds of work are readily calculated.

Electric Testing Apparatus.

On the ground floor of Building No. 10, two rooms are occupied as laboratories for investigating the electrical equipment used in mining operations. The purpose of these investigations is to ascertain the conditions under which electricity of various voltages may be used with safety—in mine haulage, hoisting, pumping, or lighting—in the presence of dangerous mixtures of explosive gases or of dust. It is

also proposed to test various kinds of insulation and insulators in this laboratory, and to determine the durability of such insulation in the presence of such corrosive gases and water as are found in mines.

A water-proof wooden tank, measuring 15 by 5 by 5 ft., is installed, in which insulation and insulating materials are tested under either pure or polluted water. Various electric lighting devices and equipment can be connected from a switch-board in Building No. 17 with Gas-and-Dust Gallery No. 2, for testing the effect of such lighting apparatus in the presence of explosive mixtures of gas and dust, as set forth on page 389.

In the electrical laboratory, Building No. 10, is a booster set developing 60 kw., and an appropriate switch-board for taking direct current at 220 volts from the turbo-generator and converting it into current varying from 0 to 750 volts. There are also transformers for developing 60-cycle, alternating current at voltages of from 110 to 2 200. The switch-board is designed to handle these various voltages and to communicate them to the apparatus under test in Building No. 10, Gallery No. 2, or elsewhere.

Tests are in progress of insulating materials for use in mines, and of electric switches, lights, etc., in Gallery No. 2 (Fig. 3, Plate LIII), and in the lamp-testing box (Fig. 2, Plate LIV). It is proposed, at the earliest possible date, to make comparative tests of the safety of various mine locomotives and mine-hoisting equipment through the medium of this laboratory, and it is believed that the results will furnish valuable information as a guide to the safety, reliability, and durability of these appliances when electrically operated.

Electric Lamp and Fuse Testing Box.—An apparatus for testing safety lamps and electric lights and fuses, consists of ¼-in. iron plates, bolted together with 1½-in. angle-irons to form a box with inside dimensions of 18 by 18 by 24 in. The box is placed on a stand at such a height that the observation windows are on a level with the observer's eye (Fig. 2, Plate LIV), and it is connected, by a gas-pipe, with a supply of natural gas which can be measured by a gas-holder or meter alongside the box.

By the use of this apparatus the effect of explosive gas on flames, of electric sparks on explosive mixtures of gas and air, and of breaking electric lamps in an explosive mixture of gas and air, may be

studied. The safety lamps are introduced into the box from beneath, through a hole 6 in. square, covered with a hinged iron lid, admission to which is had through a flexible rubber sleeve, 20 in. long.

The behavior of the standard safety lamp and of the safety lamps undergoing test may be compared in this box as to height of flame for different percentages of methane in the air, the effect of such flames in igniting gas, etc.

In each end of the box is an opening 1 ft. square, over which may be placed a paper diaphragm held by skeleton doors, the purpose of which is to confine the gas in such a manner that, should an explosion occur, no damage would be done. In the front of the box are two plate-glass observing windows, 2⅝ by 5½ in. In the side of the box, between the two windows, is a ⅜-in. hole, which can be closed by a tap-screw, through which samples for chemical analysis are drawn.

The gasometer consists of two iron cans, the lower one being open at the top and filled with water and the upper one open at the bottom and suspended by a counterweight. The latter has attached to its upper surface a scale which moves with it, thereby measuring the amount of gas in the holder. A two-way cock permits the admission of gas into the gasometer and thence into the testing box.

Gas-and-Dust Gallery No. 2.—This gallery is constructed of sheet steel and is similar to Gallery No. 1, the length, however, being only 30 ft. and the diameter 10 ft. It rests on a concrete foundation (Fig. 3, Plate LIII). Diaphragms can be placed across either extremity, or at various sections, to confine the mixtures of gas and air in which the tests are made. The admission of gas is controlled by pipes and valves, and the gas and air can be stirred or mixed by a fan, as described for Gallery No. 1, and as shown by Fig. 1.

Gallery No. 2 is used for investigating the effect of flames of various lamps, of electric currents, motors, and coal-cutting machines, in the presence of known mixtures of explosive gas and air. It is also used for testing the length of flame of safety lamps in still air carrying various proportions of methane, and, for this purpose, is more convenient than the lamp gallery. In tests with explosive mixtures, after the device to be tested has been introduced and preparations are completed, operations are controlled from a safe distance by a switch-board in a building near-by.

Among other investigations conducted in this gallery are those of

the effect of sparks on known gas mixtures. These sparks are such as those struck from a pick on flint, but in this case they are produced by rubbing a rapidly revolving emery wheel against a steel file. The effect of a spark produced by a short circuit of known voltage, the flame from an arc lamp, etc., is also studied.

Structural Materials Investigations.

The structural materials investigations are being conducted for the purpose of determining the nature and extent of the materials available for use in the building and construction work of the Government, and how these materials may be used most efficiently.

These investigations include:

(1).—Inquiries into the distribution and local availability, near each of the building centers in the United States, of such materials as are needed by the Government.

(2).—How these materials may be used most efficiently.

(3).—Their fire-resisting qualities and strength at different temperatures.

(4).—The best and most economic methods of protecting steel by fire-resistant covering.

(5).—The most efficient methods of proportioning and mixing the aggregate, locally available, for different purposes.

(6).—The character and value of protective coatings, or of various mixes, to prevent deterioration by sea water, alkali, and other destructive agencies.

(7).—The kinds and forms of reinforcement for concrete necessary to secure the greatest strength in beams, columns, floor slabs, etc.

(8).—Investigation of the clays and of the products of clays needed in Government works, as to their strength, durability, suitability as fire-resisting materials, and the methods of analyzing and testing clay products.

(9).—Tests of building stones, and investigations as to their availability near the various building centers throughout the United States.

The operations of the Structural Materials Division include investigations into cement-making materials, constituent materials of concrete, building stones, clays, clay products, iron, steel, and miscellaneous materials of construction, for the use of the Government. The organization comprises a number of sections, including those for the

chemical and physical examination of Departmental purchases; field sampling and laboratory examination of constituent materials of concrete collected by skilled field inspectors in the neighborhood of the larger commercial and building centers; similar field sampling of building stones and of clays and clay products, offered for use in Government buildings or engineering construction; and the forwarding of such samples to the testing laboratories at St. Louis or Pittsburg for investigation and test. The investigative tests include experiments regarding destructive agencies, such as electrolysis, alkaline earths and waters, salt water, fire, and weathering; also experiments with protective and water-proofing agencies, including the various washes or patented mixtures on the market, and the methods of washing, and mixing mortars and concrete, which are likely to result in rendering such materials less pervious to water.

Investigations are also being conducted to determine the nature and extent of materials available for use in the building-construction work of the Government, and how these materials may be used most efficiently and safely. While the act authorizing this work does not permit investigations or tests for private parties, it is believed that these tests for the Government cannot fail to be of great general value. The aggregate expenditure by the Federal Government in building and engineering construction is about $40 000 000 annually. This work is being executed under so many different conditions, at points so widely separated geographically, and requires so great a variety of materials, that the problems to be solved for the Government can hardly fail to cover a large share of the needs of the Engineering Profession, State and municipal governments, and the general public.

Character of the Work.—The tests and analyses, of the materials of construction purchased by the various bureaus and departments for the use of the Government, are to determine the character, quality, suitability, and availability of the materials submitted, and to ascertain data leading to more accurate working values as a basis for better working specifications, so as to enable Government officials to use such materials with more economy and increased efficiency.

Investigative tests of materials entering into Government construction, relative to the larger problems involved in the use of materials purchased by the Government, include exhaustive study of the suitability for use, in concrete construction on the Isthmian Canal, of the

sand and stone, and of the cementing value of pozzuolanic material, found on the Isthmus; the strength, elasticity, and chemical properties of structural steel for canal lock-gates; of wire rope and cables for use in hoisting and haulage; and the most suitable sand and stone available for concrete and reinforced concrete for under-water construction, such as the retaining walls being built by the Quartermaster's Department of the Army, in San Francisco Harbor.

These tests also include investigations into the disintegrating effect of alkaline soil and water on the concrete and reinforced concrete structures of the Reclamation Service, with a view to preventing such disintegration; investigations into the proper proportions and dimensions of concrete and reinforced concrete structural columns, beams, and piers, and of walls of brick and of building stone, and of the various types of metal used for reinforcement by the Supervising Architect in the construction of public buildings; investigations into the sand, gravel, and broken stone available for local use in concrete construction, such as columns, piers, arches, floor slabs, etc., as a guide to the more economical design of public structures, and to determine the proper method of mixing the materials to render the concrete most impervious to water and resistant to weather and other destructive agencies.

Other lines of research may be stated briefly as follows:

The extent to which concrete made from cement and local materials can be most safely and efficiently used for different purposes under different conditions;

The best methods for mixing and utilizing the various constituent materials locally available for use in Government construction;

The materials suitable for the manufacture of cement on the public lands, or where the Government has planned extensive building or engineering construction work, where no cement plants now exist;

The kinds and forms of reinforcement for concrete, and the best methods of applying them in order to secure the greatest strength in compression, tension, shear, etc., in reinforced concrete beams, columns, floor slabs, etc.;

The influence of acids, oils, salts, and other foreign materials, long-continued strain, or electric currents, on the permanence of the steel in reinforced concrete;

The value of protective coatings as preventives of deterioration of structural materials by destructive agencies; and

The establishment of working stresses for various structural materials needed by the Government in its buildings.

Investigations are being made into the effects of fire and the rate of conductivity of heat on concrete and reinforced concrete, brick, tile, building stone, etc., as a guide to the use of the most suitable materials for fire-proof building construction and the proper dimensioning of fire-resistive coverings.

Investigations and tests are being made, with a view to the preparation of working specifications for use in Government construction, of bricks, tile, sand-lime brick, paving brick, sewer pipe, roofing slates, flooring tiles, cable conduits, electric insulators, architectural terra cotta, fire-brick, and all shapes of refractories and other clay products, regarding which no satisfactory data for the preparation of specifications of working values now exist.

Investigations of the clay deposits throughout the United States are in progress, to determine proper methods of converting them into building brick, tile, etc., at the most reasonable cost, and the suitability of the resulting material for erection in structural forms and to meet building requirements.

Investigations are being made in the field, of building stones locally available, and physical and chemical tests of these building stones to determine their bearing or crushing strength; the most suitable mortars for use with them; their resistance to weathering; their fire-resistive and fire-proof qualities, etc., regarding which practically no adequate information is available as a guide to Government engineering and building design.

Results Accomplished.—During one period of six months alone, more than 2 500 samples, taken from Government purchases of structural materials, were examined, of which more than 300 failed to meet the specified requirements, representing many thousands of dollars worth of inferior material rejected, which otherwise would have been paid for by the Government. These tests were the means of detecting the inferior quality of large quantities of materials delivered on contracts, and the moral effect on bidders has proven as important a factor in the maintenance of a high quality of purchases, as the saving in money.

The examination of sands, gravels, and crushed stones, as constituent materials for concrete and reinforced concrete construction, has developed data showing that certain materials, locally available near large building centers and previously regarded as inferior in quality, were, in fact, superior to other and more expensive materials which it had been proposed to use.

These investigations have represented an actual saving in the cost of construction on the work of the Isthmian Canal Commission, of the Supervising Architect, and of certain States and cities which have benefited by the information disseminated regarding these constituent materials.

Investigations of clay products, only recently inaugurated, have already resulted in the ascertainment of important facts relative to the colloid matter of clay and its measurement, and the bearing thereof on the plasticity and working values of various clays. The study of the preliminary treatment of clays difficult to handle dry, has furnished useful information regarding the drying of such clays, and concerning the fire resistance of bricks made of soft, stiff, or dried clay of various densities.

The field collection and investigation of building-stone samples have developed some important facts which had not been considered previously, relative to the effect of quarrying, in relation to the strike and dip of the bedding planes of building stone, and the strength and durability of the same material when erected in building construction. These investigations have also developed certain fundamental facts relative to the effects of blasting (as compared with channeling or cutting) on the strength and durability of quarried building stone.

Mineral Chemistry Laboratories.—Investigations and analyses of the materials of engineering and building construction are carried on at Pittsburg in four of the larger rooms of Building No. 21. In this laboratory, are conducted research investigations into the effect of alkaline waters and soils on the constituent materials of concrete available in arid regions, as related to the life and permanency of the concrete and reinforced concrete construction of the Reclamation Service. These investigations include a study of individual salts found in particular alkalis, and a study of the results of allowing solutions of various alkalis to percolate through cylinders of cement mortar and concrete. Other research analyses have to do with the investigation of

destructive and preservative agencies for concrete, reinforced concrete, and similar materials, and with the chemistry of the effects of salt water on concrete, etc. The routine chemical analyses of the constituent materials of concrete and cement-making materials, used in connection with the work conducted in the St. Louis laboratories, are made in this laboratory, as are also a large number of miscellaneous chemical analyses and investigations of reinforcement metal, the composition of building stones, and allied work.

A heat laboratory, in charge of Dr. J. K. Clement, occupies three rooms on the ground floor of Building No. 21, and is concerned chiefly with the measurement of temperatures in gas producers, in the furnaces of steam boilers, kilns, etc. The work includes determinations of the thermal conductivity of fire clays, concrete, and other building materials, and of their fire-resisting properties; measurements of the thermal expansion and specific heats of fire-bricks, porcelain, and glazes; and investigations of the effect of temperature variations on the various chemical processes which take place in the fuel bed of the gas producer, boiler furnace, etc.

The heat laboratory is equipped for the calibration of the thermometers and pyrometers, and electrical and other physical apparatus used by the various sections of the Technologic Branch.

For convenience of handling materials to and from the various purchasing officers attached to the Government bureaus, this work is housed in a laboratory on the fourth floor of the Geological Survey Building in Washington.

Large quantities and many varieties of building materials for use in public buildings under contract with the Supervising Architect's office, are submitted to the laboratory by contractors to determine whether or not they meet the specified requirements. Further examinations are made of samples submitted by superintendents of construction, representing material actually furnished by contractors. It is frequently found that the sample of material submitted by the contractor is of far better quality than that sent by the superintendent to represent deliveries. The needed constant check on deliveries is thus provided.

In addition to this work for the office of the Supervising Architect, similar work on purchases and supplies is carried on for the Isthmian Canal Commission, the Quartermaster-General's Department of the

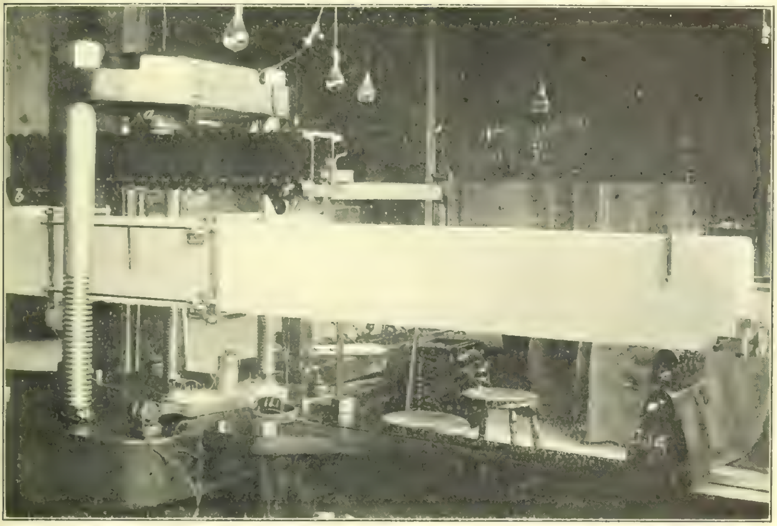


FIG. 1. TESTING BEAM IN 200 000-LB. MACHINE.

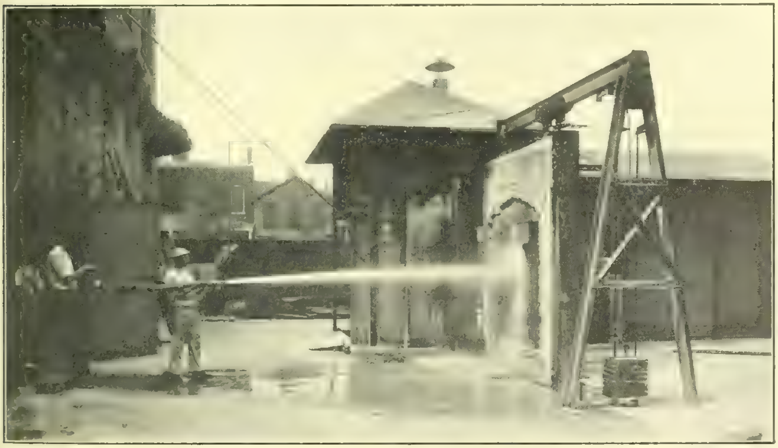


FIG. 2. FIRE TEST OF PANEL.

Army, the Life Saving Service, the Reclamation Service, and other branches of the Government. About 250 samples are examined each month, requiring an average of 12 determinations per sample, or about 3 000 determinations per month.

The chemical laboratory for testing Government purchases of structural materials, is equipped with the necessary apparatus for making the requisite physical and chemical tests. For the physical tests of cement, there are a tensile test machine, briquette moulds, a pat tank for boiling tests to determine soundness, water tanks for the storage of briquettes, a moist oven, apparatus to determine specific gravity, fineness of grinding, etc.

The chemical laboratory at Washington is equipped with the necessary analytical balances, steam ovens, baths, blast lamps, stills, etc., required in the routine chemical analysis of cement, plaster, clay, bricks and terra cotta, mineral paints and pigments, roofing material, tern plate and asphaltic compounds, water-proofing materials, iron and steel alloys, etc.

At present, materials which require investigative tests as a basis for the preparation of suitable specifications, tests not connected with the immediate determination as to whether or not the purchases are in accordance with the specifications, are referred to the chemical laboratories attached to the Structural Materials Division, at Pittsburg.

The inspection and tests of cement purchased in large quantities, such as the larger purchases on behalf of public-building construction under the Supervising Architect, or the great 4 500 000-bbl. contract of the Isthmian Canal Commission, are made in the cement-testing laboratory of the Survey, in the Lehigh Portland cement district, at Northampton, Pa.

Testing Machines.—The various structural forms into which concrete and reinforced concrete may be assembled for use in public-building construction, are undergoing investigative tests as to their compressive and tensile strength, resistance to shearing, modulus of elasticity, coefficient of expansion, fire-resistive qualities, etc. Similar tests are being conducted on building stone, clay products, and the structural forms in which steel and iron are used for building construction.

The compressive, tensile, and other large testing machines, for all kinds of structural materials reaching the testing stations, are under

the general supervision of Richard L. Humphrey, M. Am. Soc. C. E. The immediate direction of the physical tests on the larger testing machines is in charge of Mr. L. H. Losse, with Mr. H. H. Kaplan in charge of computing.

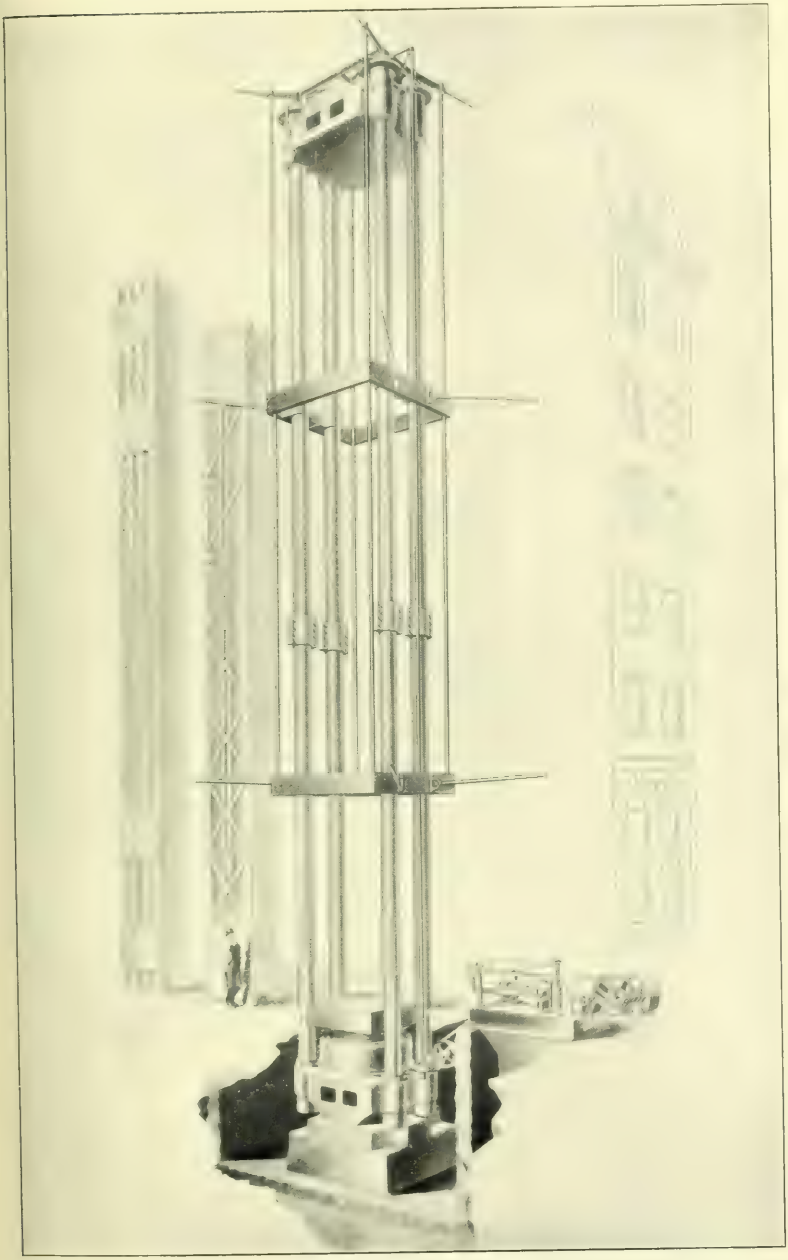
Most of this testing apparatus has been housed in buildings loaned by the City of St. Louis, in Forest Park, St. Louis, Mo., and the arrangement of these buildings, details of equipment, organization, and methods of conducting the tests, are fully set forth in Bulletin No. 329 of the U. S. Geological Survey. In brief, this equipment included motor-driven, universal, four-screw testing machines, as follows: One 600 000-lb., vertical automatic, four-screw machine; one 200 000-lb., automatic, four-screw machine; and one 200 000-lb. and one 100 000-lb. machine of the same type, but with three screws. There are a number of smaller machines of 50 000, 40 000, 10 000, and 2 000 lb., respectively.

These machines are equipped so that all are available for making tensile and compressive tests (Fig. 1, Plate LVI). The 600 000-lb. machine is capable of testing columns up to 30-ft. lengths, and of making transverse tests of beams up to 25-ft. span, and tension tests for specimens up to 24 ft. in length. The smaller machines are capable of making tension and compressive tests up to 4 ft. in length and transverse beam tests up to 20-ft. span. In addition, there are ample subsidiary apparatus, including concrete mixers with capacities of ½ and 1 cu. yd., five hollow concrete block machines, automatic sifting machines, briquette moulds, storage tanks, etc.

At the Atlantic City sub-station, there is also a 200 000-lb., universal, four-screw testing machine, with miscellaneous equipment for testing cement and moulding concrete, etc.; and at the Northampton sub-station, there is a complete equipment of apparatus for cement testing.

At the Pittsburg testing station, a 10 000 000-lb., vertical, compression testing machine (Plate LVII), made by Tinius Olsen and Company, is being erected for making a complete series of comparative tests of various building stones of 2, 4, and 12-in. cube, of stone prisms, 12 in. base and 24 in. high, of concrete and reinforced concrete columns up to 65 ft. in height, and of brick piers and structural-steel columns up to the the limits of the capacity and height of the machine.

This machine is a large hydraulic press, with an adjustable head,



10 000 000-Lb. Testing Machine.

and a weighing system for recording the loading developed by a triple-plunger pump. It has a maximum clearance of 65 ft. between heads; the clearance in the machine is a trifle more than 6 ft. between screws, and the heads are 6 ft. square.

The machine consists of a base containing the main cylinder with a sectional area of 2 000 sq. in., upon which rests the lower platform or head which is provided with a ball-and-socket bearing. The upper head is adjustable over four vertical screws, $13\frac{1}{2}$ in. in diameter and 72 ft. 2 in. long, by a system of gearing operating four nuts with ball-bearings upon which the head rests. The shafting operating this mechanism is connected with a variable-speed motor which actuates the triple-plunger pump supplying the pressure to the main cylinder (Fig. 4).

The weighing device consists of a set of standard Olsen levers for weighing one-eightieth of the total load on the main cylinder. This reduction is effected through the medium of a piston and a diaphragm. The main cylinder has a diameter of 50 in., and the smaller one, a diameter of $5\frac{9}{16}$ in. The weighing beam is balanced by an automatically-operated poise weight, and is provided with a device for applying successive counterweights of 1 000 000 lb. each. Each division on the dial is equivalent to a 100-lb. load, and smaller subdivisions are made possible by an additional needle-beam.

The power is applied by a 15-h.p., 220-volt, variable-speed motor operating a triple-plunger pump, the gearing operating the upper head being driven by the same motor. The extreme length of the main screws necessitates splicing, which is accomplished as follows:

In the center of the screws, at the splice, is a 3-in. threaded pin for centering the upper and lower screws; this splice is strengthened by sleeve nuts, split to facilitate their removal whenever it is necessary to lower the upper head; after the head has passed the splice, the sleeve nuts are replaced.

In order to maintain a constant load, a needle-valve has been provided, which, when the pump is operated at its lowest speed, will allow a sufficient quantity of oil to flow into the main cylinder to equalize whatever leakage there may be. The main cylinder has a vertical movement of 24 in. The speed of the machine, for the purpose of adjustment, using the gearing attached to the upper head, is 10 in. per min. The speed for applying loads, controlled by the variable-speed

motor driving the pump, varies from a minimum of at least $\frac{1}{60}$ in. per min. to a maximum of at least $\frac{1}{2}$ in. per min. The machine has a guaranteed accuracy of at least one-third of 1%, for any load of more than 100 000 lb., up to its capacity.

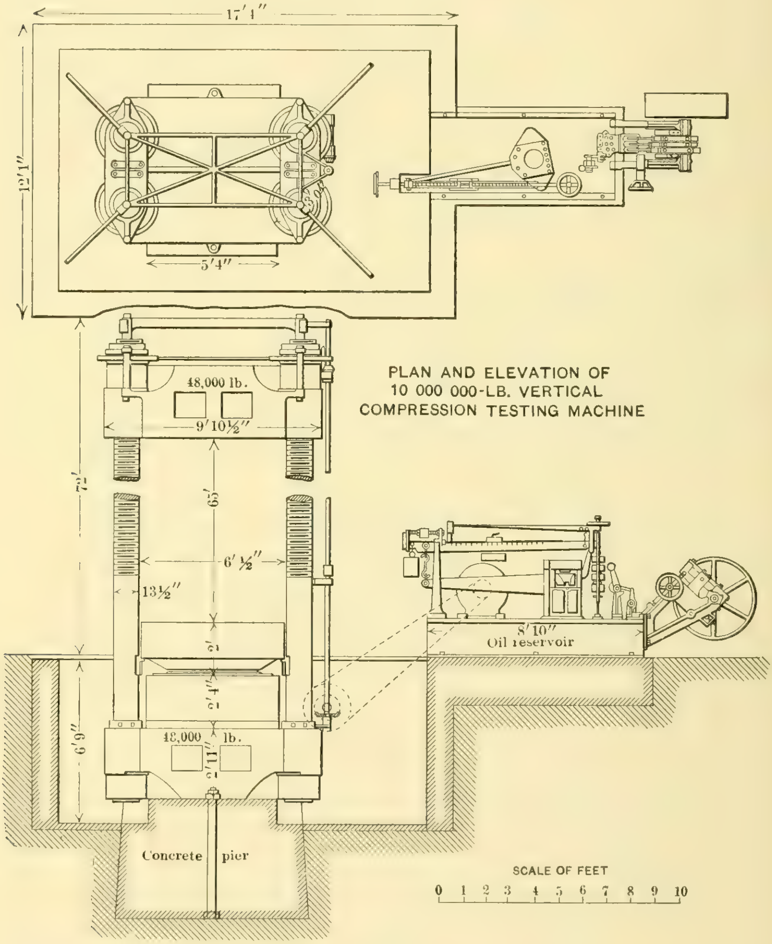


Fig. 4.

The castings for the base and the top head weigh approximately 48 000 lb. each. Each main screw weighs more than 40 000 lb., the lower platform weighing about 25 000 lb., and the main cylinder, 16 000 lb. The top of the machine will be about 70 ft. above the top

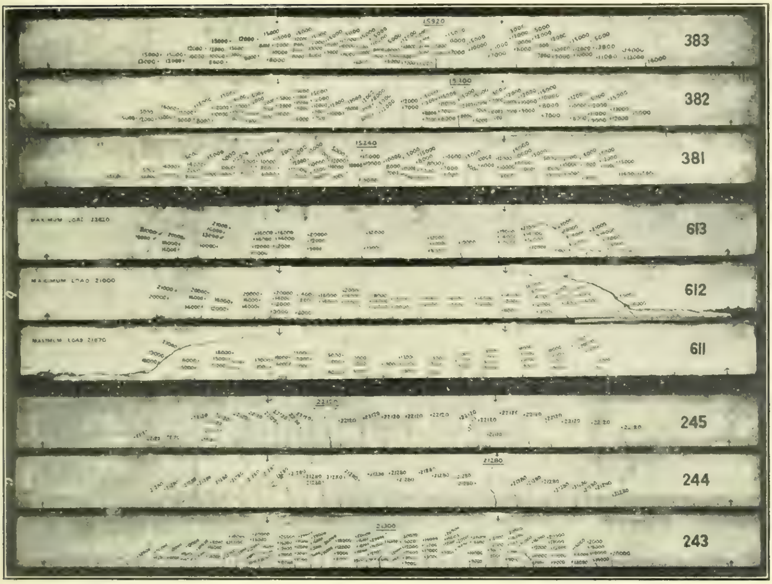


FIG. 1.—CHARACTERISTIC FAILURES OF REINFORCED CONCRETE BEAMS.

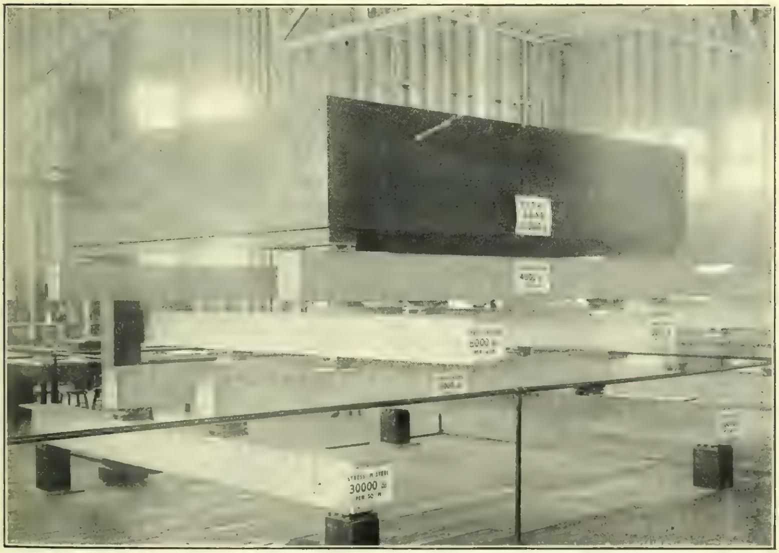


FIG. 2.—ARRANGEMENT OF STATIC LOAD TEST FOR REINFORCED CONCRETE BEAMS.

of the floor, and the concrete foundation, upon which it rests, is about 8 ft. below the floor line.

Concrete and Cement Investigations.—The investigations relating to concrete, include the examination of the deposits of sand, gravel, stone, etc., in the field, the collection of representative samples, and the shipment of these samples to the laboratory for analysis and test. These tests are conducted in connection with the investigation of cement mortars, made from a typical Portland cement prepared by thoroughly mixing a number of brands, each of which must meet the following requirements:

Specific gravity, not less than 3.10;

Fineness, residue not to exceed 8% on No. 100, nor 25% on No. 200 sieve;

Time of setting: Initial set, not less than 30 min.; hard set, not less than 1 hour, nor more than 10 hours.

Tensile strength: Requirements applying to neat cement and to 1 part cement with 3 parts standard sand:

Time specification.	Neat cement. Pounds.	1:3 Mix. Pounds.
24 hours in moist air	175	...
7 days (1 day in moist air, 6 days in water)	500	175
28 days (1 day in moist air, 27 days in water)	600	250

Constancy of volume: Pats of neat cement, 3 in. in diameter, ½ in. thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hours. A pat is kept in air at normal temperature and observed at intervals for at least 28 days. Another pat is kept in water maintained as near 70° Fahr. as practicable, and is observed at intervals for at least 28 days. A third pat is exposed in an atmosphere of steam above boiling water, in a loosely-closed vessel, for 5 hours. These pats must remain firm and hard and show no signs of distortion, checking, cracking, or disfiguration.

The cement shall not contain more than 1.75% of anhydrous sulphuric acid, nor more than 4% of magnesium oxide.

A test of the neat cement must be made with each mortar series for comparison of the quality of the typical Portland cement.

The constituent materials are subjected to the following examination and determinations, and, in addition, are analyzed to determine the composition and character of the stone, sand, etc.:

1.—Mineralogical examination,

2.—Specific gravity,

3.—Weight, per cubic foot,

4.—Sifting (granulometric composition),

5.—Percentage of silt and character of same,

6.—Percentage of voids,

7.—Character of stone as to percentage of absorption, porosity, permeability, compressive strength, and behavior under treatment.

Physical tests are made to determine the tensile, compressive, and transverse strengths of the cement and mortar test pieces, with various preparations of cement and various percentages of material. Tests are also made to determine porosity, permeability, volumetric changes in setting, absorption, coefficient of expansion, effect of oil, etc.

Investigation of concretes made from mixtures of typical Portland cement, sand, stone, and gravel, includes tests on cylinders, prisms, cubes, and other standard test pieces, with various proportions of materials and at ages ranging from 30 to 360 days. Full-sized plain concrete beams, moulded building blocks, reinforced concrete beams, columns, floor slabs, arches, etc., are tested to determine the effect, character, and amount of reinforcement, the effect of changes in volume, size, and composition, and the effect of different methods of loading and of supporting these pieces, etc.

These investigations include detailed inquiry in the field and research in the chemical and physical laboratories regarding the effects of alkaline soils and waters on structures of concrete being built by the Reclamation Service in the arid regions. It has been noted that on certain of the Reclamation projects, notably on the Sun River Project, near Great Falls, Mont., the Shoshone Project, near Cody, Wyo., and the Carlsbad and Hondo Projects in the Pecos Valley, N. Mex., structures of concrete, reinforced concrete, building stones, brick, and tile, show evidence of disintegration. This is attributed to the effects of alkaline waters or soils coming into contact with the structures, or to the constituent materials used. In co-operation with the Reclamation Service, samples of the waters, soils, and constituent materials, are collected in the field, and are subjected to careful chemical examination in the mineral laboratories at Pittsburg.

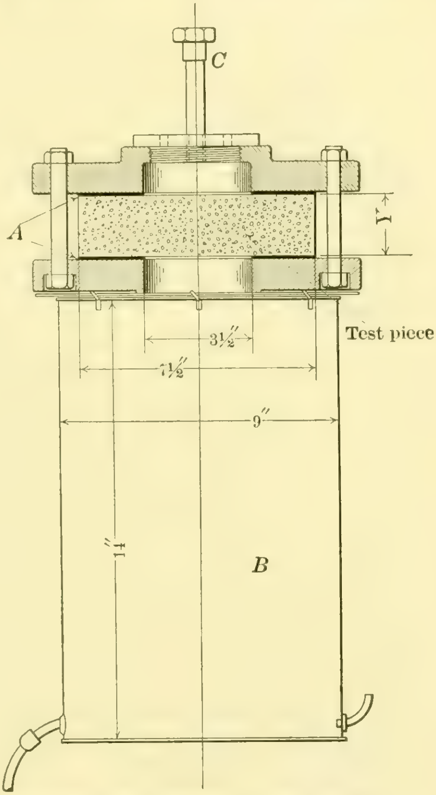
The cylinders used in the percolation tests are composed of typical Portland cement mixed with sand, gravel, and broken stone of known composition and behavior, and of cement mixed with sand, gravel, and

broken stone collected in the neighborhood of the Reclamation projects under investigation.

It is also proposed to subject these test pieces, some made with water of known purity, and others with alkaline water, to contact with alkaline soils near the projects, and with soil of known composition near the testing laboratories at Pittsburg. As these tests progress and other lines of investigation are developed, the programme will be extended, in the hope that the inquiry may develop methods of preparing and mixing concrete and reinforced concrete which can be used in alkaline soils without danger of disintegration.

Investigations into the effect of salt water on cement mortars and concretes, and the effect of electrolysis, are being conducted at Atlantic City, N. J., where the test pieces may be immersed in deep sea water for longer or shorter periods of time.

At the St. Louis laboratory a great amount of investigative work was done for the purpose of determining the suitability and availability of various structural materials submitted for use by the Government. While primarily valuable only to the Government, the results of these tests are of indirect value to all who are interested in the use of similar materials. Among such investigations have been those relating to the strength, elasticity, and chemical properties of wire rope for use in the Canal Zone; investigations of the suitability and cementing value of con-



CROSS-SECTION OF APPARATUS FOR HOLDING PERMEABILITY-TEST PIECES.

Fig. 5.

crete, sand, stone, and pozzuolanic material found on the Isthmus; investigations as to the relative resistance to corrosion of various types of wire screens for use in the Canal Zone; into the suitability for use, in concrete sea-wall construction, of sand and stone from the vicinity of San Francisco; into the properties of reinforced concrete floor slabs; routine tests of reinforcing metal, and of reinforced concrete beams and columns, for the Supervising Architect of the Treasury Department, etc. The results have been set forth in three bulletins which describe the methods of conducting these tests and also tests on constituent materials of concrete and plain concrete beams. In addition, there are in process of publication a number of bulletins giving the results of tests on reinforced concrete beams, columns, and floor slabs, concrete building blocks, etc.

The Northampton laboratory was established there because it is in the center of the Lehigh cement district, and therefore available for the mill sampling and testing of purchases of cement made by the Isthmian Canal Commission, but also available for tests of cement purchased in the Lehigh district, by the Supervising Architect and others. It is in a building, the outer walls of which are of cement plaster applied over metal lath nailed to studding. The partitions are of the same construction, and the floors and roof are of concrete throughout.

The inspection at the factories and the sampling of the cement are under the immediate direction of the Commission; the testing is under the direction of the U. S. Geological Survey. A large force of employees is required, in view of the magnitude of the work, which includes the daily testing of consignments ranging from 5 000 to 10 000 bbl., sampled in lots of 100 bbl., which is equivalent to from 50 to 100 samples tested per day.

The cement to be sampled is taken from the storage bins and kept under seal by the chief inspector pending the results of the test. The quantity of cement sampled is sufficient for the tests required under the specifications of the Isthmian Canal Commission, as well as for preliminary tests made by the cement company, and check tests made at the Geological Survey laboratory, at Pittsburg.

The tests specified by the Commission include determination of specific gravity, fineness of grinding, time of setting, soundness, tensile strength (with three parts of standard quartz sand for 7 and 28 days,

respectively), and determination of sulphur anhydride (SO_3), and magnesia (MgO).

The briquette-making and testing room is fitted with a mixing table, moist closet, briquette-storage tanks, and testing machines. The mixing table has a concrete top, in which is set plate glass, 18 in. square and 1 in. thick. Underneath the table are shelves for moulds, glass plates, etc.

The moist closet, 5 ft. high, 3 ft. 10 in. wide, and 1 ft. 8 in. deep, is divided into two compartments by a vertical partition, and each compartment is fitted with cleats for supporting thirteen tiers of glass plates. On each pair of cleats, in each compartment, can be placed four glass plates, each plate containing a 4-gang mould, making storage for 416 briquettes. With the exception of the doors, which are of wood lined with copper, the closet is of 1 : 1 cement mortar, poured monolithic, even to the cleats for supporting the glass plates.

The immersion tanks, of the same mortar, are in tiers of three, supported by a steel structure. They are 6½ ft. long, 2½ ft. wide, and 6 in. deep, and 2 000 briquettes can be stored in each tank. The overflow from the top tank wastes into the second, which, in turn, wastes into the third. Water is kept running constantly.

The briquette-testing machine is a Fairbanks shot machine with a capacity of 2 000 lb., and is regulated to apply load at the rate of 600 lb. per min. Twenty-four 4-gang moulds, of the type recommended by the Special Committee on Uniform Tests of Cement, of the American Society of Civil Engineers, are used.

The room for noting time of set and soundness is fitted with a mixing table similar to that in the briquette-making room. The Vicat apparatus is used for determining the normal consistency, and the Gilmore apparatus for the time of setting. While setting, the soundness pats are stored in galvanized-iron pans having about 1 in. of water in the bottom, and covered with dampened felt or burlap. The pats rest on a rack slightly above the water and well below the felt.

For specific gravity tests, the Le Chatelier bottles are used. A pan, in which five bottles can be immersed at one time, is used for maintaining the benzine at a constant temperature. The samples are weighed on a pair of Troemner's No. 7 scales.

The fineness room is fitted with tables, two sets of standard No.

100 and No. 200 sieves, and two Troemner's No. 7 scales similar to those used for the specific gravity tests.

The storage room is fitted with shelves for the storage of samples being held for 28-day tests.

The mould-cleaning room contains tables for cleaning moulds, and racks for air pats.

An effort is made to keep all the rooms at a temperature of 70° Fahr., and, with this in view, a Bristol recording thermometer is placed in the briquette-room. Two wet-and-dry bulb hygrometers are used to determine the moisture in the air.

Samples are taken from the conveyor which carries the cement to the storage bins, at the approximate rate of one sample for each 100 bbl. After each 4 000-bbl. bin has been filled, it is sealed until all tests have been made, when, if these have been satisfactory, it is released for shipment.

The samples are taken in cans, 9 in. high and 7½ in. in diameter. These cans are delivered in the preparation room where the contents are mixed and passed through a No. 20 sieve. Separate samples are then weighed out for mortar briquettes, for soundness pats, and for the specific-gravity and fineness tests. These are placed in smaller cans and a quantity sufficient for a re-test is held in the storage room awaiting the results of all the tests.

The sample for briquettes is mixed with three parts standard crushed quartz, and then taken to the briquette-making room, where eight briquettes are made, four for 7-day and four for 28-day tests. These are placed in the moist closet in damp air for 24 hours, then removed from the moulds, and placed in water for the remainder of the test period. At the proper time they are taken from the immersion tank and broken.

From the sample for soundness, four pats are made. The time of setting is determined on one of these pats. They are placed in the pan previously described, for 24 hours, then one is placed in running water and one in air for 28 days. The others are treated in the boiler, one in boiling water for 3 hours and one in steam at atmospheric pressure for 5 hours.

The sample taken for specific gravity and fineness is dried in the oven at 100° cent. in order to drive off moisture. Two samples are then carefully weighed out, 50 grammes for fineness and 64 grammes

for specific gravity, and the determinations are made. As soon as anything unsatisfactory develops, a re-test is made. If, however, the cement satisfies all requirements, a report sheet containing all the data for a bin, is made out, and the cement is ready for shipment. From every fifth bin, special neat and mortar briquettes are made, which are intended for tests at ages up to ten years.

Salt-Water Laboratory.—The laboratory at Atlantic City, for conducting investigations into the effects of salt water on concrete and reinforced concrete, is situated so that water more than 25 ft. deep is available for immersion tests of the setting and deterioration of such materials.

Through the courtesy of the municipality of Atlantic City, Young's cottage, and old Young's Pier, has been turned over, at a nominal rental, to the Geological Survey for the conduct of these tests. The laboratory building is about 700 ft. from the boardwalk, and occupies a space about 100 by 45 ft. It is one story high, of frame-cottage construction, and stands on wooden piles at one side of the pier proper and about 20 ft. above the water, which is about 19 ft. deep at this point. Fresh running water, gas, electric light, and electric power are supplied to the building (Fig. 6).

In this laboratory investigations will be made of the cause of the failure and disintegration of cement and concrete subjected to the action of sea water. Tests are conducted so as to approach, as nearly as possible, the actual conditions found in concrete construction along the sea coast. All sea-water tests are made in the ocean, some will probably be paralleled by ocean-water laboratory tests and all by fresh-water comparative tests.

Cements, in the form of pats, briquettes, cubes, cylinders, and in a loose ground state, and also mortars and concretes in cube, cylinder, and slab form, are subjected to sea water.

The general plan for the investigations is as follows:

1.—Determination of the failing elements and the nature of the failure;

2.—Determination of the value of the theories advanced at the present time; and,

3.—Determination of a method of eliminating or chemically recombining the injurious elements.

Preliminary tests are in progress, including a study of the effect

of salt water on mortars and concretes of various mixtures and ages. The proportions of these mixtures and the methods of mixing will be varied from time to time, as suggested by the progress of the tests.

Fire-Proofing Tests.—Tests of the fire-proofing and fire-resistive properties of various structural materials are carried on in the laboratories in Building No. 10, at Pittsburg, and in co-operation with the Board or Fire Underwriters at its Chicago laboratory (Fig. 2, Plate LVI). These tests include three essential classes of material: (*a*), clay products, protective coverings representative of numerous varieties of brick and fire-proofing tiles, including those on the market and those especially manufactured for these tests in the laboratory at Pittsburg; (*b*), characteristic granites of New England, with subsequent tests of the various building stones found throughout the United States; and (*c*), cement and concrete covering material, building blocks, and concrete reinforced by steel bars embedded at different depths for the purpose of studying the effect of expansion on the protective covering.

In co-operation with the physical laboratory, these tests include a study of the relative rates of conductivity of cement mortars and concretes. By embedding thermocouples in cylinders composed of the materials under test, obtaining a given temperature by an electric coil, and noting the time required to raise the temperature at the various embedded couples to a given degree, the rate of conductivity may be determined. Other tests include those in muffles to determine the rate of expansion and the effect of heat and compressive stresses combined on the compressive strength of the various structural materials. The methods of making the panel tests, and the equipment used, are described and illustrated in Bulletin No. 329, and the results of the tests have been published in detail in Bulletin No. 370 of the Geological Survey.

Building Stones Investigations.—The field investigations of building stones are conducted by Mr. E. F. Burchard, and include the examination of the various deposits found throughout the United States. A study of the granites of New England has been commenced, which includes the collection of type specimens of fine, medium, and coarse-grained granites, and of dark, medium, and light-gray or white granites. A comparative series of these granites, consisting of prisms and cubes of 4 and 2 in., respectively, has been prepared.

PLAN OF LABORATORY FOR SALT-WATER TESTS AT ATLANTIC CITY, N. J.

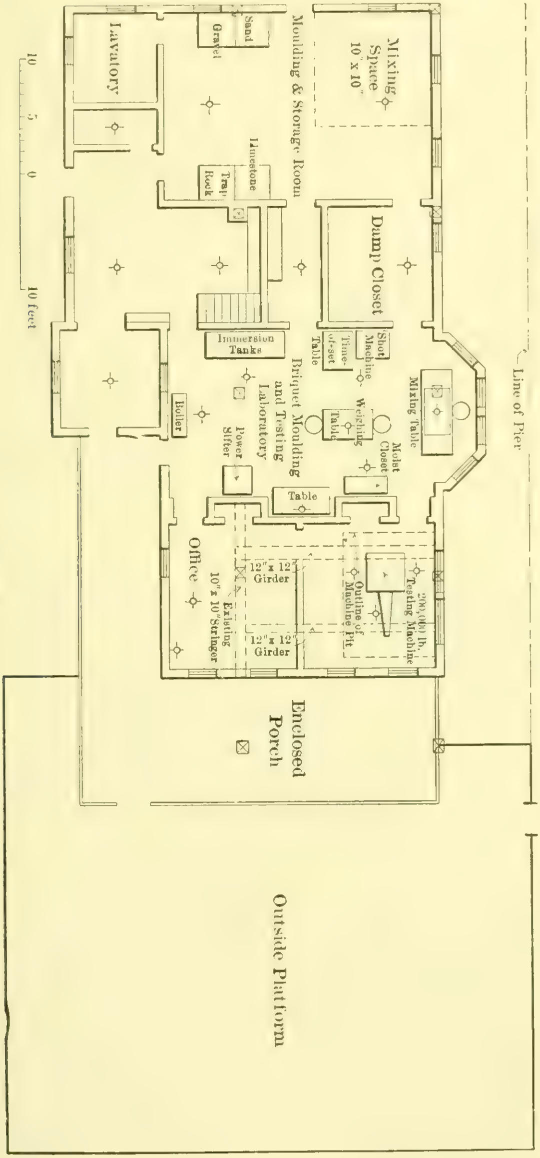


FIG. 6.

The standard adopted for compressive test pieces in the 10 000 000-lb. machine is a prism, having a base of 12 in. and being 24 in. high. The tests include not only those for compression or crushing strength, but also those for resistance to compressive strains of the prisms and cubes, when raised to high temperatures in muffles or kilns; resistance to weathering, freezing, and thawing; porosity; fire-resisting qualities, etc.

In collecting field samples, special attention is paid to the occurrence of the stone, extent of the deposit, strike, dip, etc., and specimens are procured having their faces cut with reference to the bedding planes, in order that compressive and weathering tests may be made, not only in relation to these planes but at those angles thereto in which the material is most frequently used commercially. Attention is also paid to the results of blasting, in its relation to compressive strains, as blasting is believed to have a material effect on stones, especially on those which may occur in the foundations of great masonry dams, and type specimens of stone quarried by channeling, as well as by blasting, are collected and tested.

Clay and Clay Products Investigations.—These investigations are in charge of Mr. A. V. Bleininger, and include the study of the occurrence of clay beds in various parts of the United States, and the adaptability of each clay to the manufacture of the various clay products.

Experiments on grinding, drying, and burning the materials are conducted at the Pittsburg testing station, to ascertain the most favorable conditions for preparing and burning each clay, and to determine the most suitable economic use to which it may be put, such as the manufacture of building or paving bricks, architectural tiles, sewer tiles, etc.

The laboratory is equipped with various grinding and drying devices, muffles, kilns, and apparatus for chemical investigations, physical tests, and the manufacture and subsequent investigative tests of clay products.

This section occupies the east end of Building No. 10, and rooms on the first and second floors have been allotted for this work. In addition, a brick structure, 46 by 30 ft., provided with a 60-ft. iron stack, has been erected for housing the necessary kilns and furnaces.

On the ground floor of Building No. 10, adjoining the cement and

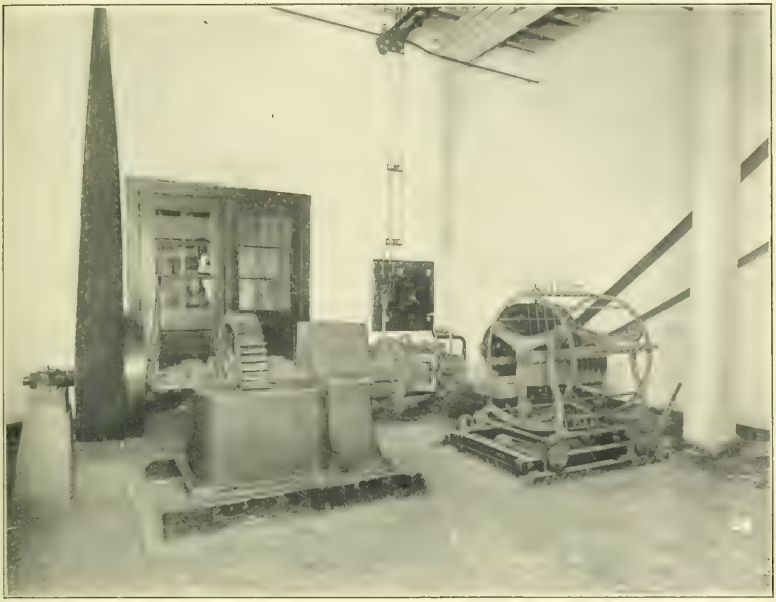


FIG. 1.—BRICK MACHINE AND UNIVERSAL CUTTER.

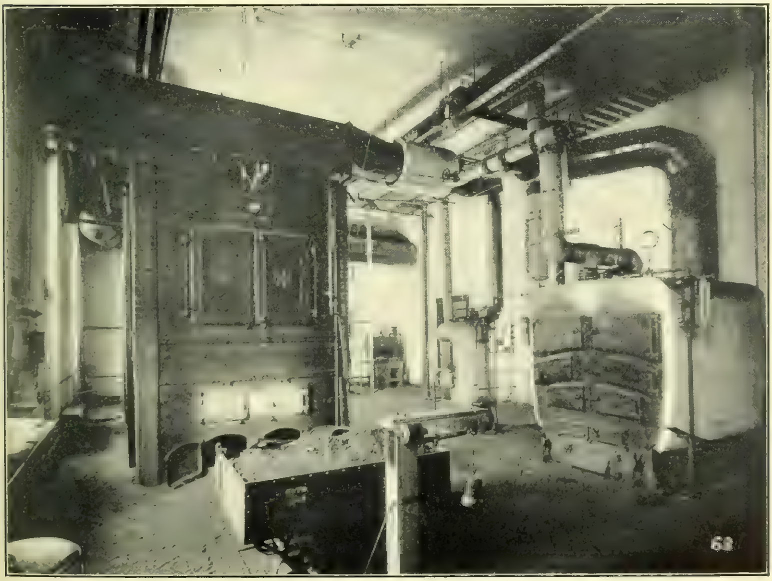


FIG. 2.—HOUSE-HEATING BOILER, BUILDING NO. 21.

concrete section, is a storage room for raw materials and products under investigation. Adjoining this room and connecting with it by wide doors, is the grinding room, containing a 5-ft. wet pan, with 2 000-lb. rollers, to be used for both dry and wet grinding. Later, a heavy dry pan is to be installed. With these machines, even the hardest material can be easily disintegrated and prepared. In this room there is also a jaw crusher for reducing smaller quantities of very hard material, as well as a 30 by 16-in. iron ball mill, for fine grinding. These machines are belted to a line shaft along the wall across the building. Ample sink drainage is provided for flushing and cleaning the wet pan, when changing from one clay to another.

A large room adjoining is for the operation of all moulding and shaping machines, representing the usual commercial processes. At present these include an auger machine, with a rotary universal brick and tile cutter, Fig. 1, Plate LIX, and a set of brick and special dies, a hand repress for paving brick, and a hand-screw press for dry pressing. The brick machine is operated from the main shaft which crosses the building in this room and is driven from a 50-h.p. motor. It is possible thus to study the power consumption under different loads and with different clays, as well as with varying degrees of water content in the clay. As the needs of the work demand it, other types of machines are to be installed. For special tests in which pressure is an important factor it is intended to fit up one of the compression testing machines of the cement section with the necessary dies, thus enabling the pressing to be carried on under known pressures. Crushing, transverse, and other tests of clay products are made on the testing machines of the cement and concrete laboratories.

Outside of the building, in a lean-to, there is a double-chamber rattler for the testing of paving brick according to the specifications of the National Brick Manufacturers' Association.

In the smaller room adjoining the machine laboratory there are two small wet-grinding ball mills, of two and four jars, respectively, and also a 9-leaf laboratory filter press.

The remaining room on the first floor is devoted to the drying of clays and clay wares. The equipment consists of a large sheet-iron drying oven of special construction, which permits of close regulation of the temperature (Fig. 7). It is heated by gas burners, and is used for the preliminary heat treatment of raw clays, in connection with

the study of the drying problems of certain raw materials. It is intended to work with temperatures as high as 250° cent.

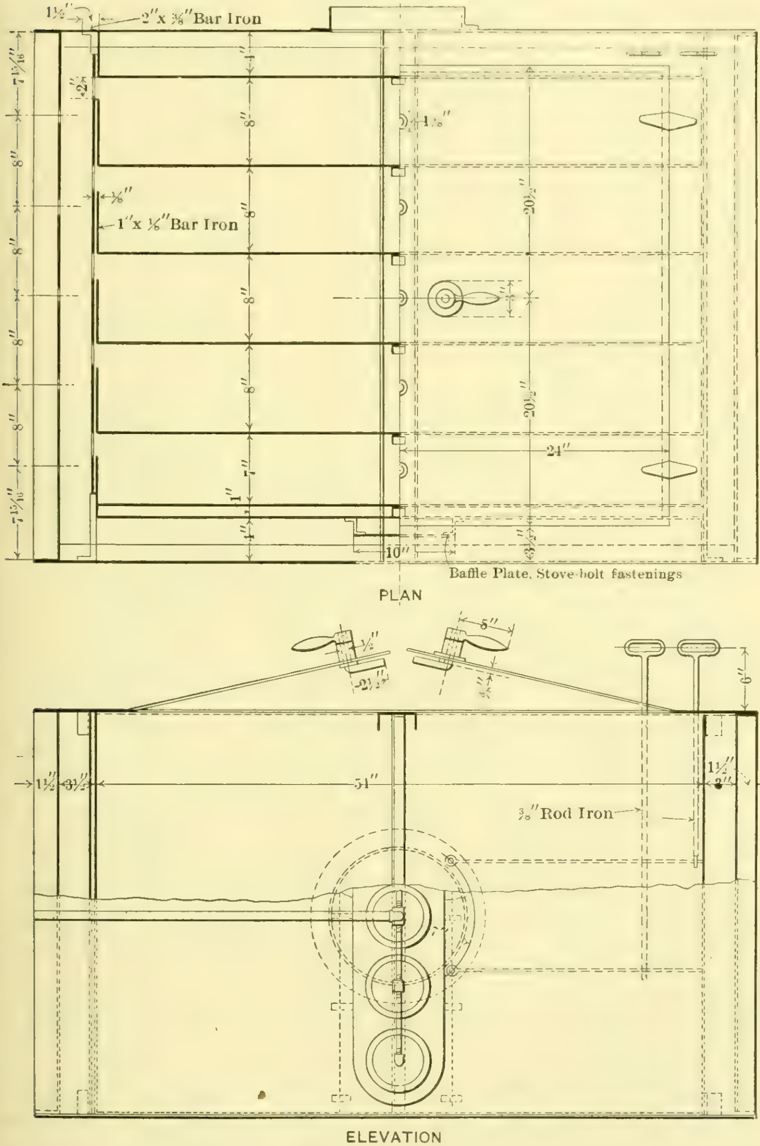
Another drying closet, heated by steam coils (Fig. 8), intended for drying various clay products, has been designed with special reference to the exact regulation of the temperature, humidity, and velocity of the air flowing through it. Both dryers connect by flues with an iron stack outside the building. This stack is provided with a suction fan, driven by a belt from an electric motor.

On the second floor are the chemical, physical, and research laboratories, dealing with the precise manipulations of the tests and investigations.

The chemical laboratory is fully equipped with the necessary apparatus for carrying on special chemical research in silicate chemistry, including electrical resistance furnaces, shaking devices, etc. It is not the intention to do routine work in this laboratory. The office adjoins this laboratory, and near it is the physical laboratory, devoted to the study of the structure of raw materials. The latter contains Nobel and Schoene elutriators, together with viscosimeters of the flow and the Coulomb types, sieves, voluminometers, colorimeters, vernier shrinkage gauges, micrometers, microscopes, and the necessary balances.

The room across the hall is devoted to the study of the specific gravity, absorption, porosity, permeability, hardness, translucency, etc., of burnt-clay products, all the necessary apparatus being provided. In the two remaining rooms, intended for research work, special apparatus adapted to the particular investigation may be set up. All the rooms are piped for water, gas, compressed air, steam, and drainage, and wired for light and power.

In the kiln house there is a test kiln adapted for solid fuel and gas. It is of the down-draft type, with an available burning space of about 8 cu. ft. (Fig. 9). For heavier ware and the study of the fire behavior of clay products under conditions approaching those of practice, a round down-draft kiln, with an inside diameter of 6 ft., is to be built. About 13 ft. above the floor level, and supported by iron beams, there is a flue parallel to the long side of the structure. This flue conducts the gases of the kilns to the stack, which is symmetrically located with reference to the kiln house. Natural gas is the principal fuel. In addition to these kilns, a small muffle furnace, fired with



CLAY-DRYING OVEN

12 0 12 Inches

Fig. 7.

petroleum, is provided for the determination of melting points, and an electric carbon resistance furnace, with an aluminum muffle for high-temperature work. For crucible-fusion work, a gas-fired pot furnace is installed.

Along the north wall, bins are provided for the storage of fuel, clay, sand, and other kiln supplies. There are two floor drainage sinks, and electric current, steam, water, and compressed air, are provided.

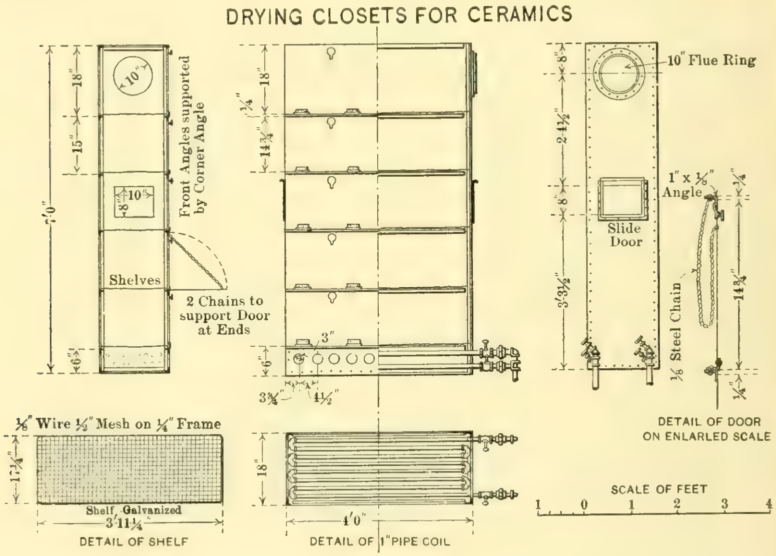


Fig. 8.

Results of the Work.—More than 39 300 separate test pieces have been made at the structural-materials testing laboratory. In connection with the study of these, 86 000 tests and nearly 14 000 chemical analyses have been made. Of these tests more than 13 600 have been of the constituent materials of concrete, including tensile tests of cement briquettes, compression tests of cylinders and cubes, and transverse tests of various specimens.

Nearly 1 200 beams of concrete or reinforced concrete, each 13 ft. long and 8 by 11 in. in cross-section, have been made, and, in connection with the investigation of the behavior of these beams, nearly 3 000 tests have been made. Nearly 900 of these beams, probably more than double the entire number made in other laboratories in

the United States, during a period of more than 15 years, have been tested.

In the section of building blocks, 2 200 blocks have been tested, including, with auxiliary pieces, more than 4 500 tests; also, more than 900 pieces of concrete have been tested for permeability and shear. The physical tests have numbered 14 000; tests of steel for reinforcement, 3 800; and 550 tests to determine fire-resistive qualities of various building materials, have been made on 30 special panels, and on miscellaneous pieces.

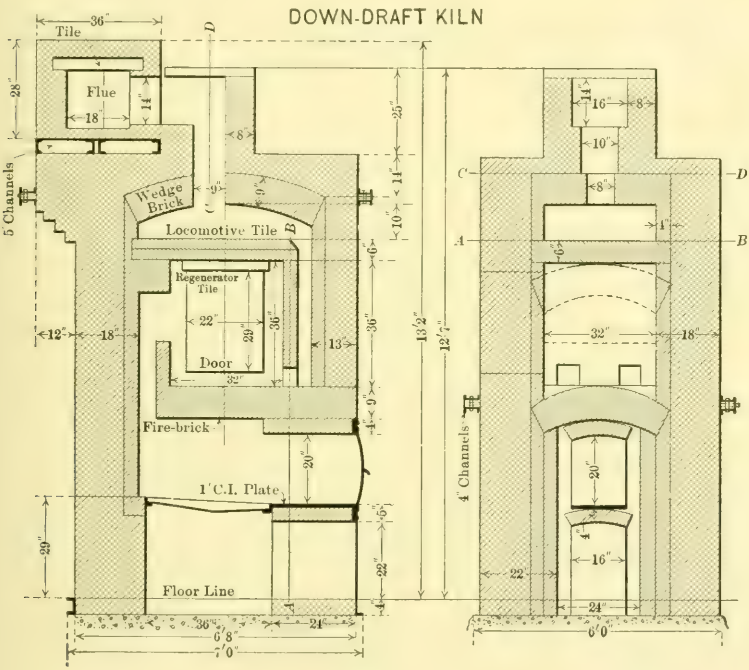


FIG. 9.

The tests of the permeability of cement mortars and concretes, and of water-proofing and damp-proofing materials, have numbered 3 470.

The results of the work of the Structural Materials Division have already appeared in preliminary bulletins, as follows: No. 324, "San Francisco Earthquake and Fire of April 18, 1906, and Their Effects on Structures and Structural Materials"; No. 329, "Organization, Equipment, and Operation of the Structural-Materials Testing Laboratories

at St. Louis, Mo."; No. 331, "Portland Cement Mortars and Their Constituent Materials" (based on nearly 25 000 tests); No. 344, "Strength of Concrete Beams" (based on tests of 108 beams); No. 370, "Fire-Resistive Properties of Various Building Materials"; No. 387, "The Colloid Matter of Clay and its Measurements." A bulletin on the results of tests of reinforced concrete beams, one on the manufacture and chemistry of lime, and one on drying tests of brick, are in course of publication.

Fuel Investigations.

The scope of the fuel investigations has been planned to conform to the provisions of the Act of Congress which provides for analyzing and testing coals, lignites, and other mineral fuel substances belonging to the United States, or for the use of the United States Government, and examinations for the purpose of increasing the general efficiency or available supply of the fuel resources in the United States.

In conformity with this plan, the investigations inaugurated at St. Louis had for their initial object the analyzing and testing of the coals of the United States, using in this work samples of from 1 to 3 carloads, collected with great care from typical localities in the more important coal fields of the country, with a view to determining the relative values of those different fuels. In the work at Norfolk, during 1907, this purpose was modified to the extent of keeping in view relative fuel efficiencies for naval purposes. The tests at Denver have been on coal from Government land or from land contiguous thereto, and are conducted solely with a view to perfecting methods of coking this coal by prior washing and by manipulation in the process of coking.

Three general lines of inquiry are embodied in the plan of investigation undertaken and contemplated by the Technologic Branch, after conference and with the advice and approval of the Advisory Board: 1. The ascertainment of the best mode of utilizing any fuel deposit owned or to be used by the Government, or the fuel of any extensive deposit as a whole, by conducting a more thorough investigation into its combustion under steam boilers, conversion into producer gas, or into coke, briquettes, etc. 2. The prevention of waste, through the study of the possibility of improvement in the methods of mining, shipping, utilizing, etc. 3. The inspection and analysis of coal and

lignite purchased under specification for the use of the Government, to ascertain its heating value, ash, contained moisture, etc.

The first general line of work concerns the investigation and testing of the fuel resources of the United States, and especially those belonging to the Federal Government, to determine a more efficient and more economical method of utilizing the same. This work has developed along the following lines:

The collection of representative samples for chemical analysis, and calorimeter tests by a corps of skilled mine samplers, from the mines selected as typical of extensive deposits of coal in a given field or from a given bed of coal; and the collection from the same mines of larger samples of from 1 to 3 carloads, shipped to the testing station for tests in boiler furnaces, gas producers, etc., as a check on the analysis and calorimeter tests;

The testing of each coal received to determine the most efficient and least wasteful method of use in different furnaces suitable for public buildings or power plants or ships of the Government;

The testing of other portions of the same shipment of coal in the gas producer, for continuous runs during periods of a few days up to several weeks, in order to determine the availability of this fuel for use in such producers, and the best method of handling it, to determine the conditions requisite to produce the largest amount of high-grade gas available for power purposes;

The testing of another portion of the same coal in a briquette machine at different pressures and with different percentages and kinds of binder, in order to determine the feasibility of briquetting the slack or fine coal. Combustion tests are then made of these briquettes, to determine the conditions under which they may be burned advantageously;

Demonstrations, on a commercial scale, of the possibility of producing briquettes from American lignites, and the relative value of these for purposes of combustion as compared with the run-of-mine coal from which the briquettes are made;

The finding of cheaper binders for use in briquetting friable coals not suited for coking purposes;

Investigations into the distribution, chemical composition, and calorific value of the peat deposits available in those portions of the United States where coal is not found, and the preparation of such

peat for combustion, by drying or briquetting, to render it useful as a local substitute for coal;

Investigations into the character of the various petroleums found throughout the United States, with a view to determining their calorific value, chemical composition, and the various methods whereby they may be made most economically available for more efficient use as power producers, through the various methods of combustion;

Investigations and tests into the relative efficiency, as power producers in internal-combustion engines, of the heavier distillates of petroleum, as well as of kerosene and gasoline, in order to ascertain the commercial value and relative efficiency of each product in the various types of engines;

Investigations into the most efficient methods of utilizing the various coals available throughout the United States for heating small public buildings, army posts, etc., in order that these coals may be used more economically than at present;

Investigative studies into the processes of combustion within boiler furnaces and gas producers to ascertain the temperatures at which the most complete combustion of the gases takes place, and the means whereby such temperatures may be produced and maintained, thus diminishing the loss of values up the smokestack and the amount of smoke produced;

Investigations and tests into the possibilities of coking coals which have hitherto been classed as non-coking, and the making of comparative tests of all coals found in the United States, especially those from the public lands of the West;

Investigations, by means of washing in suitable machines, to determine the possibility of improving the quality of American coals for various methods of combustion, and with a view to making them more available for the production of coke of high-grade metallurgical value, as free as possible from sulphur and other injurious substances.

At each stage of the process of testing, samples of the coal have been forwarded to the chemical laboratory for analyses; combustion temperatures have been measured; and samples of gas collected from various parts of the combustion chambers of the gas producers and boiler furnaces have been analyzed, in order that a study of these data may throw such light on the processes of combustion and indicate such necessary changes in the apparatus, as might result in larger economies in the use of coal.

The second line of investigation concerns the methods of mining and preparing coal for the market, and the collection of mine samples of coal, oil, etc., for analysis and testing. It is well known that, under present methods of mining, from 10 to 75% of any given deposit of coal is left underground as props and supports, or as low-grade material, or in overlying beds broken up through mining the lower bed first. An average of 50% of the coal is thus wasted or rendered valueless, as it cannot be removed subsequently because of the caving or falling in of the roofs of abandoned galleries and the breaking up of the adjoining overlying beds, including coal, floor, and roof.

The investigations into waste in mining and the testing of the waste, bone, and slack coal in gas producers, as briquettes, etc., have, for their purpose, the prevention of this form of waste by demonstrating that these materials, now wasted, may be used profitably, by means of the gas producers and engines, for power purposes.

The third general line of investigation concerns the inspection and sampling of fuel delivered to the Government under purchase contracts, and the analyzing and testing of the samples collected, to determine their heating value and the extent to which they may or may not comply with the specifications under which they are purchased. The coal delivered at the public buildings in the District of Columbia are sampled by special representatives of the Technologic Branch of the Survey. The taking of similar samples at public buildings and posts throughout the United States, and the shipment of the samples in hermetically sealed cans or jars to the chemical laboratory at Washington, is for the most part looked after by special officers or employees at each place. These purchases are made, to an increasing extent, under specifications which provide premiums for coal delivered in excess of standards, and penalties for deliveries below standards fixed in the specifications. The standard for bituminous coals is based mainly on the heat units, ash, and sulphur, while that for anthracite coal is, for convenience, based mainly on the percentage of ash.

In connection with all these lines of fuel testing, certain research work, both chemical and physical, is carried on to determine the true composition and properties of the different varieties of coal, the changes in the transformation from peat to lignite, from lignite to bituminous coal, and from bituminous to anthracite coal, and the chemical and physical processes in combustion. Experiments are conducted concerning the destructive distillation of fuels; the by-products of coking

processes; the spontaneous combustion of coal; the storage of coal, and the loss in value in various methods of storing; and kindred questions, such as the weathering of coal. These experiments may yield valuable results through careful chemical research work supplemented by equally careful observations in the field.

Inspection and Mine Sampling.—In the Geological Survey Building, at Washington, coal purchased for Government use on a guaranteed-analysis or heat-value basis, is inspected and sampled. All samples of fuels required in the investigation at the Pittsburg plant and elsewhere are obtained by employees of this section.

COAL-SAMPLING ROOM, GEOLOGICAL SURVEY, WASHINGTON, D.C.

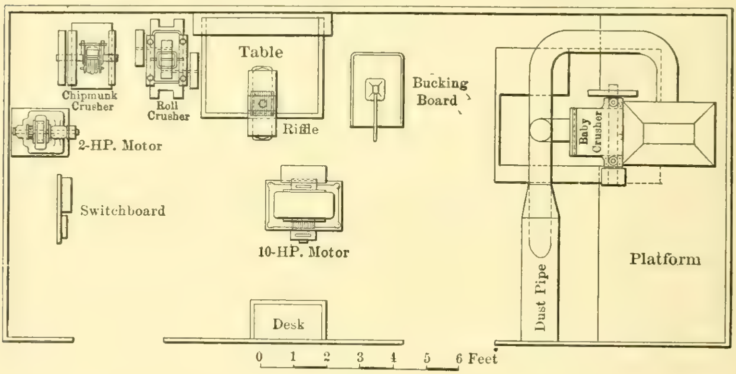


Fig. 10.

Some of the employees on this work are constantly at the mines taking samples, or at public works inspecting coal for Government use, while others are stationed at Washington to look after the deliveries of coal to the many public buildings, and to collect and prepare samples taken from these deliveries for analysis, as well as to prepare samples received from public works and buildings in other parts of the country.

The preparation of these samples is carried on in a room in the basement of the building, where special machinery has been installed for this work. Fig. 10 shows a plan of this room and the arrangement of the sampling and crushing machinery.

The crushing of the coal produces great quantities of objectionable dust, and to prevent this dust from giving trouble outside the sampling room, the wooden partitions on three sides of the room (the fourth side being a masonry wall) are completely covered on the outside with

galvanized sheet iron. The only openings to the room are two doors, which are likewise covered with sheet iron, and provided with broad flanges of the same material, in order to seal effectually the openings when the doors are shut. Fresh air is drawn into the room by a fan, through a pipe leading to the outer air. A dust-collecting system which carries the coal dust and spent air from the room, consists of an arrangement of 8-in. and 12-in. pipes leading from hoods, placed over the crushing machines, to the main furnace stack of the building. The draft in this stack draws all the dust from the crushers directly through the hoods to the main pipe, where most of it is deposited.

The equipment of the sampling room consists of one motor-driven, baby hammer crusher, which has a capacity of about 1 ton per hour and crushes to a fineness of ¼-in. mesh; one adjustable chipmunk jaw crusher, for 5- and 10-lb. samples; one set of 4½ by 7½-in. rolls, crushing to 60 mesh, for small samples; one large bucking board, and several different sizes of riffle samplers for reducing samples to small quantities. The small crushers are belted to a shaft driven by a separate motor from that driving the baby crusher.

In conducting the inspection of departmental purchases of coal in Washington, the office is notified whenever a delivery of coal is to be made at one of the buildings, and an inspector is sent, who remains during the unloading of the coal. He is provided with galvanized-iron buckets having lids and locks; each bucket holds about 60 lb. of coal. In these buckets he puts small quantities of the coal taken from every portion of the delivery, and when the delivery has been completed, he locks the buckets and notifies the office to send a wagon for them. The buckets are numbered consecutively, and the inspector makes a record of these numbers, the date, point of delivery, quality of coal delivered, etc. The buckets are also tagged to prevent error. He then reports to the office in person, or by telephone, for assignment to another point in the city. All the samples are delivered to the crushing room in the basement of the Survey Building, to be prepared for analysis.

Samples taken from coal delivered to points outside of Washington are taken by representatives of the department for which the coal is being purchased, according to instructions furnished them, and, from time to time, the regular inspectors are sent to see that these instructions are being complied with. These samples are crushed by hand, reduced to about 2 lb. at the point where they are taken, and sent

to Washington, in proper air-tight containers, by mail or express, accompanied by appropriate descriptions.

Each sample is entered in the sample record book when received, and is given a serial number. For each contract a card is provided giving information relative to the contract. On this card is also entered the serial number of each sample of coal delivered under that contract.

After the samples are recorded, they are sent to the crushing room, where they are reduced to the proper bulk and fineness for analysis. They are then sent, in rubber-stoppered bottles, accompanied by blank analysis report cards and card receipts, one for each sample, showing the serial numbers, to the Laboratory of Departmental Purchases for analysis. The receipt card for each sample is signed and returned to the inspection office, and when the analysis has been made, the analysis report card showing the result is returned. This result is entered at once on the contract card, and when all analyses have been received, covering the entire delivery of coal, the average quality is calculated, and the results are reported to the proper department.

The matter of supplying the Pittsburg plant with fuel for test purposes is also carried on from the Washington office. Preliminary to a series of investigations, the kinds and amounts of coal required are decided on, and the localities from which these coals are to be obtained are determined. Negotiations are then opened with the mine owners, who, in most cases, generously donate the coal. When the preliminaries have been arranged, an inspector is sent to the mine to supervise the loading and shipment of the coal. This inspector enters the mine and takes, for chemical analysis, small mine samples which are sent to the laboratory at Pittsburg in metal cans by mail, accompanied by proper identification cards. The results of the analysis are furnished to the experts in charge at the testing plant, for their information and guidance in the investigations for which the coal was shipped.

All samples for testing purposes are designated consecutively in the order of shipment, "Pittsburg No. 1," "Pittsburg No. 2," etc. A complete record of all shipments is kept on card forms at the Pittsburg plant, and a duplicate set of these is on file in the inspection office at Washington.

Analysis of Fuels.—The routine analyses of fuel used in the com-

bustion tests at Pittsburg, and of the gases resulting from combustion or from explosions in the testing galleries, or sampled in the mines, are made in Building No. 21. A small laboratory is also maintained on the second floor of the south end of Building No. 13, for analyses of gases resulting from combustion in the producer-gas plant, and from explosions in Galleries Nos. 1 and 2, etc. From four to six chemists are continually employed in this laboratory (in 8-hour shifts), during prolonged gas-producer tests, and three chemists are also employed in analyzing gases relating to mine explosions.

In addition to these gas analyses, there are also made in the main laboratory, analyses and calorific tests of all coal samples collected by the Geological Survey in connection with its land-classification work on the coal lands of the Western States. Routine analyses of mine, car, and furnace samples of fuels for testing, before and after washing and briquetting, before coking and the resultant coke, and extraction analyses of binders for briquettes, etc., are also made in this laboratory.

The fuel-testing laboratory at Washington is equipped with two Mahler bomb calorimeters and the necessary balances and chemical equipment required in the proximate analysis of coal. More than 225 deliveries of coal are sampled each month for tests, representing 50 000 tons purchased per month, besides daily deliveries, on shipboard, of 600 000 tons of coal for the Panama Railroad. The data obtained by these tests furnish the basis for payment. The tests cover deliveries of coal to the forty odd bureaus, and to the District Municipal Building in Washington; to the arsenals at Watertown, Mass., Frankford, Pa., and Rock Island, Ill.; and to a number of navy yards, through the Bureau of Yards and Docks; to military posts in various parts of the country, through the Quartermaster-General's Department; to the Reclamation Service, through its purchasing officer in Chicago; to several lighthouse districts; and to the superintendents of the various public buildings throughout the United States, through the Treasury Department; etc. During 1909, the average rate of reporting fuel samples was 540 per month, requiring, on an average, six determinations per sample, or about 3 240 determinations per month.

Fuel-Research Laboratories.—Smaller laboratories, occupying, on the average, three rooms each, are located in Building No. 21. One is used for chemical investigations and calorific tests of petroleum collected from the various oil fields of the United States; another is used

for investigations relative to the extraction of coal and the rapidity of oxidization of coals by standard solutions of oxidizing agents; and another is occupied with investigations into the destructive distillation of coal. The researches under way show the wide variation in chemical composition and calorific value of the various crude oils, indicate the possibility of the extraction of coal constituents by solvents, and point to important results relative to the equilibrium of gases at high temperatures in furnaces and gas producers. The investigations also bear directly on the coking processes, especially the by-product process, as showing the varying proportion of each of the volatile products derivable from types of coals occurring in the various coal fields of the United States, the time and temperature at which these distillates are given off, the variation in quality and quantity of the products, according to the conditions of temperature, and, in addition, explain the deterioration of coals in storage, etc.

At the Washington office, microscopic investigations into the life history of coal, lignite, and peat are being conducted. These investigations have already progressed far enough to admit of the identification of some of the botanical constituents of the older peats and the younger lignites, and it is believed that the origin of the older lignites, and even of some of the more recent bituminous coals, may be developed through this examination.

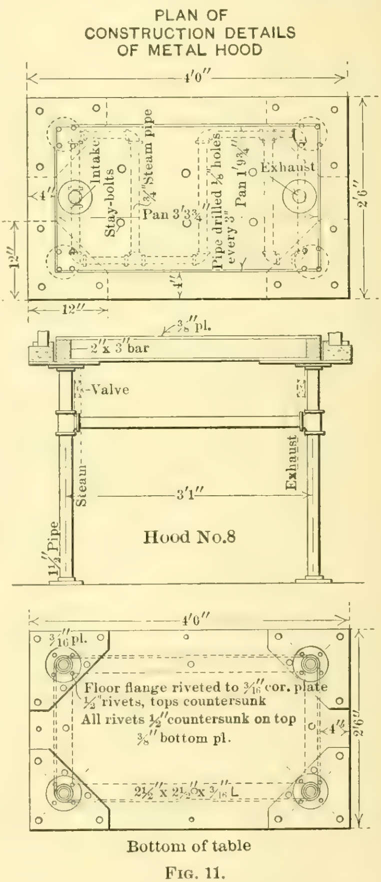


FIG. 11.

In the chemical laboratories, in Building No. 21, the hoods (Figs. 11 and 12) are of iron, with a brick pan underneath. They are supported on iron pipes, as are most of the other fixtures in the laboratories

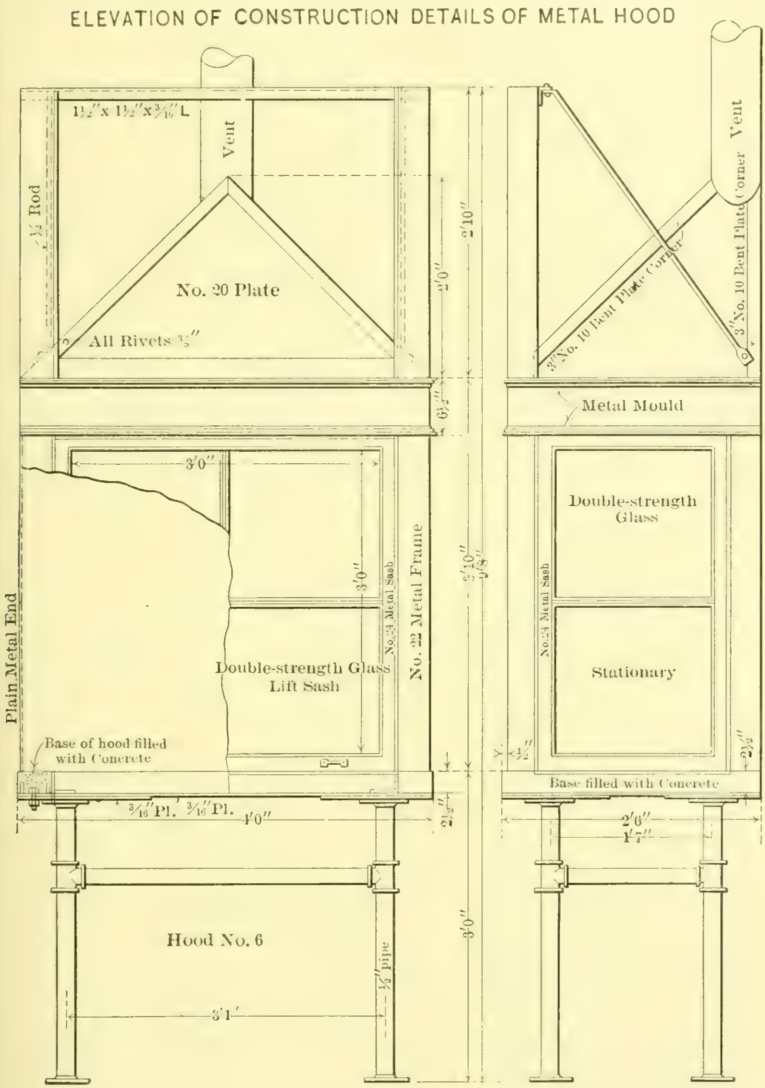

ELEVATION OF CONSTRUCTION DETAILS OF METAL HOOD
1½"x 1½"x 3/16" L
Vent
½ Rod
No. 20 Plate
All Rivets ⅜"
2'0"
2'10"
6½"
Metal Mould
3" No. 10 Bent Plate Corner
3" No. 10 Bent Plate Corner
Vent
3'0"
3'0"
2'10"
9'8"
No. 22 Metal Frame
No. 24 Metal Sash
Plain Metal End
Double-strength Glass
Lift Sash
Double-strength Glass
Stationary
Base of hood filled with Concrete
Base filled with Concrete
3/16" Pl.
3/16" Pl.
4'0"
2½"
2½"
2'6"
1'7"
Hood No. 6
½" pipe
3'0"
3'1"

Fig. 12.

in this building. The hood proper is of japanned, pressed-iron plate, No. 22 gauge, the same material being used for the boxes, slides, and bottom surrounding the hood. The sash is hung on red copper pulleys, and the corners of the hood are reinforced with pressed, japanned, riveted plate to which the ventilating pipe is riveted.

There is some variety in the cupboards and tables provided in the various laboratories, but, in general, they follow the design shown in Fig. 13. The table tops, 12 ft. long, are of clear maple in full-length pieces, $\frac{7}{8}$ in. thick and $2\frac{5}{8}$ in. wide, laid on edge and drilled at 18-in. intervals for bolts. These pieces are glued and drawn together by the bolts, the heads of which are countersunk. The tops, planed off, sanded, and rounded, are supported on pipe legs and frames of $1\frac{1}{4}$ by $1\frac{1}{2}$-in. galvanized-iron pipe with screw flanges fitting to the floor and top. Under the tops are drawers and above them re-agent shelves. Half-way between the table top and the floor is a wire shelf of a frame-work of No. 2 wire interlaced with No. 12 weave of $\frac{5}{8}$-in. square mesh.

Certain of the tables used in the laboratory are fitted with cupboards beneath and with drawers, and, in place of re-agent stands, porcelain-lined sinks are sunk into them. These tables follow, in general style and construction, the re-agent tables. The tables used in connection with calorimeter determinations are illustrated in Fig. 14. The sinks provided throughout these laboratories are of standard porcelain enamel, rolled rim, 18 by 13 in., with enameled back, over a sink and drain board, 24 in. long on the left side, though there are variations from this type in some instances.

The plumbing includes separate lines of pipe to each hood and table; one each for cold water, steam at from 5 to 10 lb. pressure, compressed air, natural gas, and, in some cases, live steam at a pressure of 60 lb.

On each table is an exposed drainage system of $2\frac{1}{2}$-in. galvanized-iron pipe, in the upper surface of which holes have been bored, through which the various apparatus drain by means of flexible connections of glass or rubber. These pipes and the sinks, etc., discharge into main drains, hung to the ceiling of the floor beneath. These drains are of wood, asphaltum coated, with an inside diameter ranging from 3 to 6 in., and at the proper grades to secure free discharge. These wooden drain-pipes are made in short lengths, strengthened by a spiral wrapping of metal bands, and are tested to a pressure of 40 lb. per sq. in. Angles are turned and branches connected in 4- and 6-in. square headers.

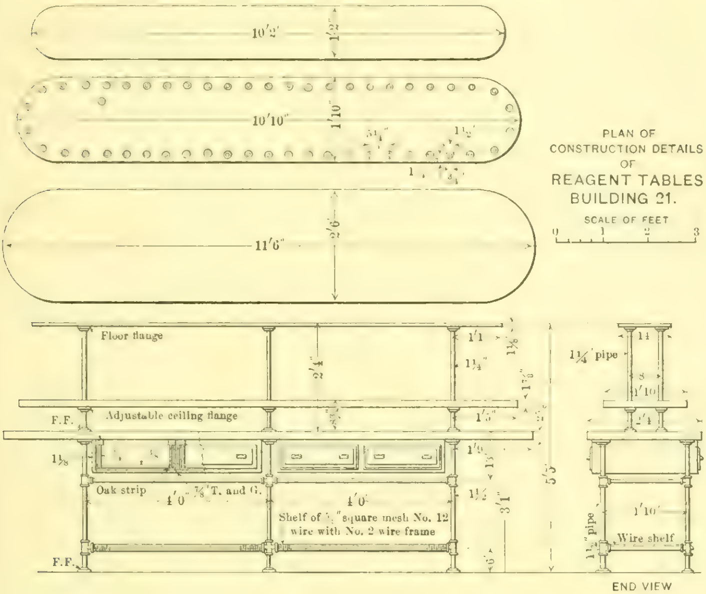


Fig. 13.

CONSTRUCTION DETAILS OF CALORIMETER TABLES

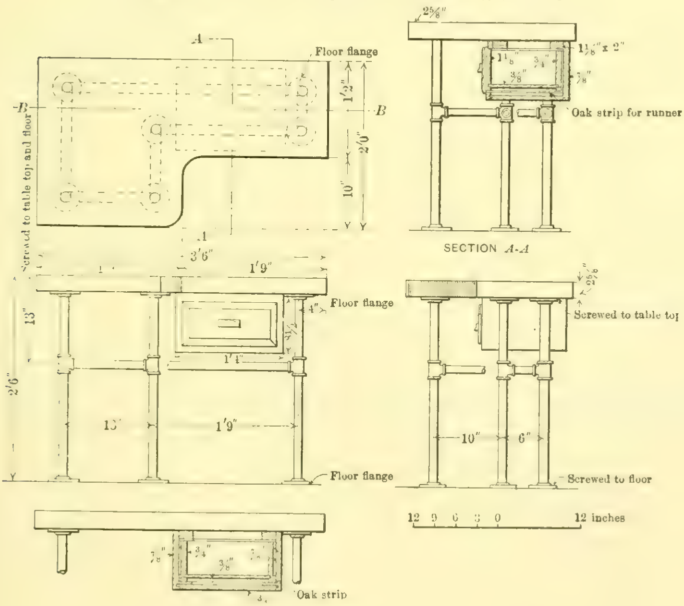


Fig. 14.

The entire building is ventilated by a force or blower fan in the basement, and by an exhaust fan in the attic with sufficient capacity to insure complete renewal of air in each laboratory once in 20 min.

The blower fan is placed in the center of the building, on the ground floor, and is 100 in. in diameter. Its capacity is about 30 000 cu. ft. of air per min., and it forces the air, through a series of pipes, into registers placed in each of the laboratories.

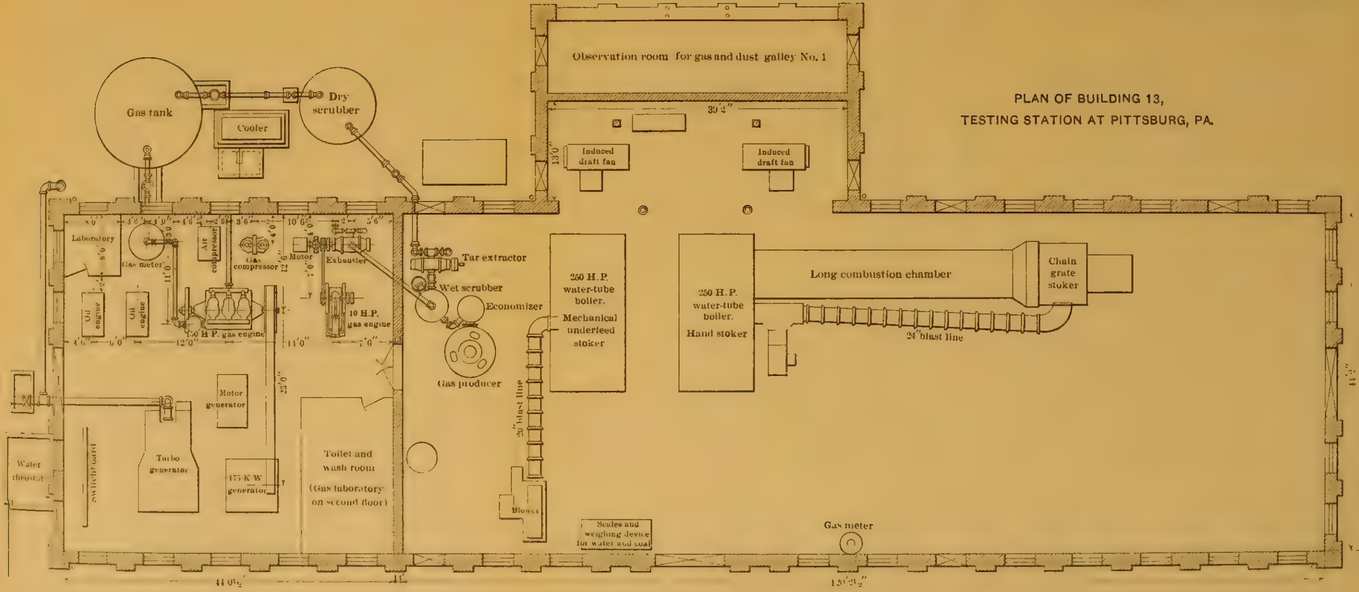
The exhaust fan, in the center of the attic, is run at 550 rev. per min., and has a capacity of 22 600 cu. ft. of air per. min. It draws the air from each of the rooms below, as well as from the hoods, through a main pipe, 48 in. in diameter.

Steaming and Combustion Tests.—The investigations included under the term, fuel efficiency, relate to the utilization of the various types of fuels found in the coal fields, and deal primarily with the combustion of such fuels in gas producers, in the furnaces of steam boilers, in locomotives, etc., and with the efficiency and utilization of petroleum, kerosene, gasoline, etc., in internal-combustion engines. This work is under the general direction of Mr. R. L. Fernald, and is conducted principally in Buildings Nos. 13 (Plate LX) and 21.

For tests of combustion of fuels purchased by the Government, the equipment consists of two Heine, water-tube boilers, each of 210 h.p., set in Building No. 13. One of these boilers is equipped with a Jones underfeed stoker, and is baffled in the regular way. At four points in the setting, large pipes have been built into the brick wall, to permit making observations on the temperature of the gas, and to take samples of the gas for chemical analysis.

The other boiler is set with a plain hand-fired grate. It is baffled to give an extra passage for the gases (Fig. 15). Through the side of this boiler, at the rear end, the gases from the long combustion chamber enter and take the same course as those from the hand-fired grate. Both the hand-fired grate and the long combustion chamber may be operated at the same time, but it is expected that usually only one will be in operation. A forced-draft fan has been installed at one side of the hand-fired boiler, to provide air pressure when coal is being burned at high capacity. This fan is also connected in such a way as to furnish air for the long combustion chamber when desired. A more complete description of the boilers may be found in Professional Paper No. 48, and Bulletin No. 325, in which the water-measuring apparatus is also described.

PLAN OF BUILDING 13,
TESTING STATION AT PITTSBURG, PA.



On account of the distance from Building No. 21 to the main group of buildings, it was considered inadvisable to attempt to furnish steam from Building No. 13 to Building No. 21, either for heating or power purposes. In view, moreover, of the necessity of installing various types and sizes of house-heating boilers, on account of tests to be made thereon in connection with these investigations, it was decided to install these boilers in the lower floor of Building No. 21, where they could be utilized, not only in making the necessary tests, but in furnishing heat and steam for the building and the chemical laboratories therein.

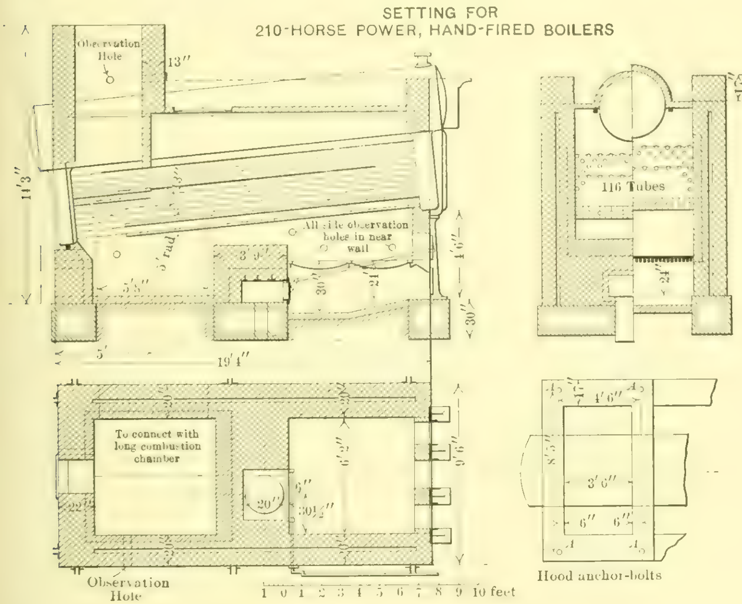


FIG. 15.

In addition to the physical laboratory on the lower floor of Building No. 21, and the house-heating boiler plant with the necessary coal storage, there are rooms devoted to the storage of heavy supplies, samples of fuels and oils, and miscellaneous commercial apparatus. One room is occupied by the ventilating fan and one is used for the necessary crushers, rolls, etc., required in connection with the sampling of coal prior to analysis.

The Quartermaster's Department having expressed a wish that tests be made of the heating value and efficiency of the various fuels

offered that Department, in connection with the heating of military posts throughout the country, three house-heating boilers were procured which represent, in a general way, the types and sizes used in a medium-sized hospital or other similar building, and in smaller residences (Fig. 2, Plate LIX). The larger apparatus is a horizontal return-tubular boiler, 60 in. in diameter, 16 ft. long, and having fifty-four 4-in. tubes.

In order to determine whether such a boiler may be operated under heating conditions without making smoke, when burning various kinds of coal, it has been installed in accordance with accepted ideas regarding the prevention of smoke. A fire-brick arch extends over the entire grate surface and past the bridge wall. A baffle wall has been built in the combustion chamber, which compels the gases to pass downward and to divide through two openings before they reach the boiler shell. Provision has been made for the admission of air at the front of the furnace, underneath the arch, and at the rear end of the bridge wall, thus furnishing air both above and below the fire. It is not expected that all coals can be burned without smoke in this furnace, but it is desirable to determine under what conditions some kinds of coals may be burned without objectionable smoke.

For sampling the gases in the smokebox of the horizontal return-tubular boiler, a special flue-gas sampler was designed, in order to obtain a composite sample of the gases escaping from the boiler.

The other heaters are two cast-iron house-heating boilers. One can supply 400 sq. ft. of radiation and the other about 4 000 sq. ft. They were installed primarily for the purpose of testing coals to determine their relative value when burned for heating purposes. They are piped to a specially designed separator, and from this to a pressure-reducing valve. Beyond this valve an orifice allows the steam to escape into the regular heating mains. This arrangement makes it possible to maintain a practically constant load on the boilers.

There is a fourth boiler, designed and built for testing purposes by the Quartermaster's Department. This is a tubular boiler designed on the lines of a house-heating boiler, but for use as a calorimeter to determine the relative heat value of different fuels reduced to the basis of a standard cord of oak wood.

A series of research tests on the processes of combustion is being conducted in Building No. 13, by Mr. Henry Kreisinger. These

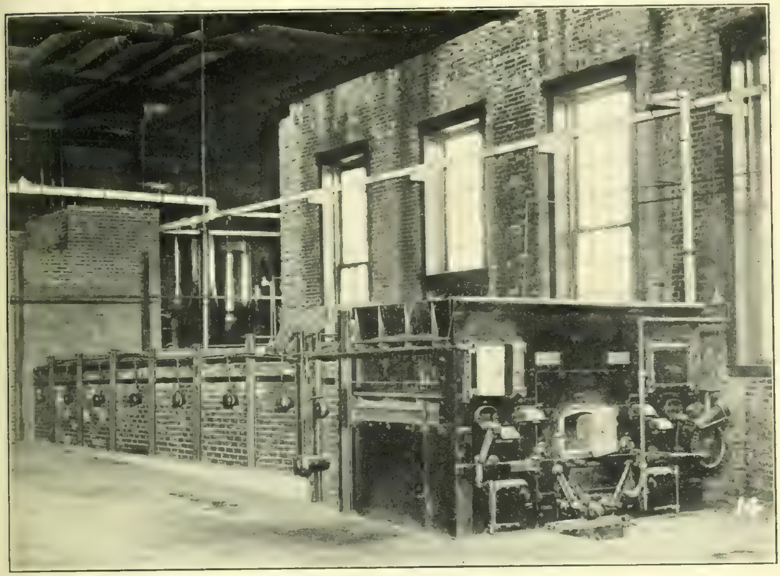


FIG. 1.—LONG COMBUSTION CHAMBER.

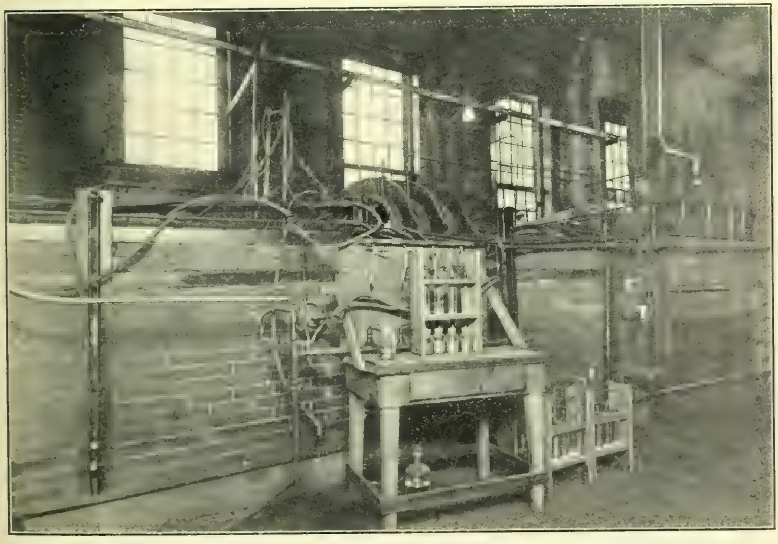


FIG. 2.—GAS SAMPLING APPARATUS, LONG COMBUSTION CHAMBER.

tests are being made chiefly in a long combustion chamber (Figs. 16 and 17, and Figs. 1 and 2, Plate LXI), which is fed with hot gases from a Murphy mechanical stoker, and discharges these at the rear end of the combustion chamber, into the hand-fired Heine boiler. The walls and roof of this chamber are double; the inner wall is 9 in. thick, of fire-brick; the outer one is 8 in. thick, and is faced with red pressed brick. Between the walls of the sides there is a 2-in. air space, and between them on the roof a 1-in. layer of asbestos paste is placed. The inner walls and roof have three special slip-joints, to allow for expansion. The floor is of concrete, protected by a 1½-in. layer of asbestos board, which in turn is covered by a 3-in. layer of earth; on top of this earth there is a 4-in. layer of fire-brick (not shown in the drawings).

CROSS-SECTIONS OF CHAMBER AND OF FURNACE,
LONG COMBUSTION CHAMBER

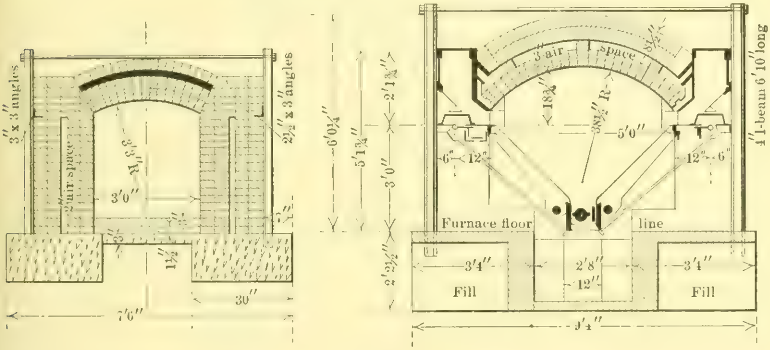


FIG. 16.

Inasmuch as one of the first problems to be attacked will be the determination of the length of travel and the time required to complete combustion in a flame in which the lines of stream flow are nearly parallel, great care was taken to make the inner surfaces of the tunnel smooth, and all corners and hollows are rounded out in the direction of travel of the gases.

Provision is made, by large peep-holes in the sides, and by smaller sampling holes in the top, for observing the fuel bed at several points and also the flame at 5-ft. intervals along the tunnel. Temperatures and gas samples are taken simultaneously at a number of points through these holes, so as to determine, if possible, the progress of combustion (Fig. 1, Plate LXI).

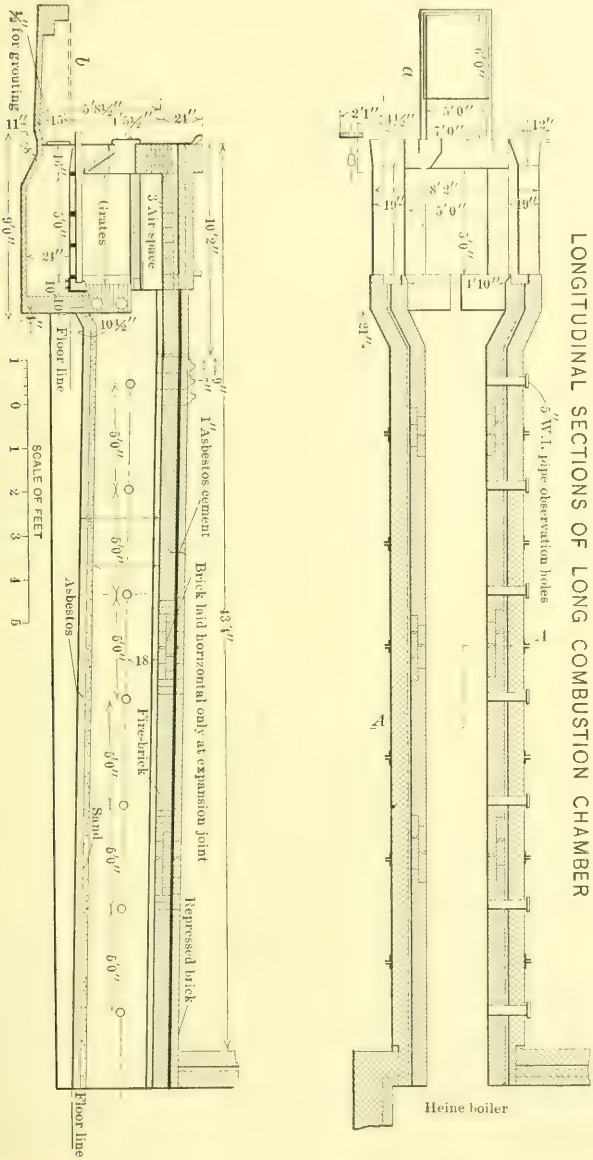
About twenty thermo-couples are embedded in the walls, roof, and floor, some within 1 in. of the inside edge of the tunnel walls, and some in the red pressed brick near the outer surface, the object of which is to procure data on heat conduction through well-built brick walls (Fig. 2, Plate LXI).

In order to minimize the leakage of air through the brickwork, the furnace and tunnel are kept as nearly as possible at atmospheric pressure by the combined use of pressure and exhausting fans. Nevertheless, the leakage is determined periodically as accurately as possible.

At first a number of tests were run to calibrate the apparatus as a whole, all these preliminary tests being made on cheap, carefully inspected, uniform screenings from the same seam of the same mine near Pittsburg. Later tests will be run with other coals of various volatile contents and various distillation properties.

It is anticipated that the progress of the tests may suggest changes in the construction or operation of this chamber. It is especially contemplated that the section of the chamber may be narrowed down by laying sand in the bottom and fire-brick thereon; also that baffle walls may be built into various portions of it, and that cooling surfaces with baffling may be introduced. In addition to variations in the tests, due to changes in construction in the combustion chamber, there will be variations in the fuels tested. Especial effort will be made to procure fuels ranging in volatile content from 15 to 27 and to 40%, and those high in tar and heavy hydro-carbons. It is also proposed to vary the conditions of testing by burning at high rates, such as at 15, 20, and 30 lb. per ft. of grate surface, and even higher. Records will be kept of the weight of coal fired and of each firing, of the weight of ash, etc.; samples of coal and of ash will be taken for chemical and physical analysis, as well as samples of the gas, and other essential data. These records will be studied in detail.

A series of heat-transmission tests undertaken two years ago, is being continued on the ground floor of Building No. 21, on modified apparatus reconstructed in the light of the earlier experiments by Mr. W. T. Ray. The purpose of the tests on this apparatus has been to determine some of the laws controlling the rate of transmission of heat from a hot gas to a liquid and *vice versa,* the two being on the opposite sides of a metal tube.



LONGITUDINAL SECTIONS OF LONG COMBUSTION CHAMBER

FIG. 17.

It appears that four factors determine the rate of heat impartation from the gas to any small area of the metal*:

(1).—The temperature difference between the body of the gas and the metal;

(2).—The weight of the gas per cubic foot, which is proportional to the number of molecules in any unit of volume;

(3).—The bodily velocity of the motion of the gas parallel to any small area under consideration; and (probably),

(4).—The specific heat of the gas at constant pressure.

The apparatus consists of an electric resistance furnace containing coils of nickel wire, a small (interchangeable) multi-tubular boiler, and a steam-jet apparatus for reducing the air pressure at the exit end, so as to cause a flow of air through the boiler. A surface condenser was attached to the boiler's steam outlet, the condensed steam being weighed as a check on the feed-water measurements. A number of thermometers and thermo-couples were used to obtain atmospheric-air temperature, temperatures of the air entering and leaving the boilers, and feed-water temperature.

The apparatus is now being reconstructed with appliances for measuring the quantity of air entering the furnace, and an automatic electric-furnace temperature regulator.

Three sizes of boiler have been tested thus far, the dimensions being as given in Table 4.

TABLE 4.—DIMENSIONS OF BOILERS NOS. 1, 2, AND 3.

Items.	Boiler No. 1.	Boiler No. 2.	Boiler No. 3.
Distance, outside to outside of boiler heads, in inches	8.28	8.28	16.125
Actual outside diameter of flues, in inches	0.252	0.313	0.252
Actual inside diameter of flues, in inches	0.175	0.230	0.175
Number of flues (tubes)	10	10	10

Each of the three boilers was tested at several temperatures of entering air, up to 1 500° Fahr., about ten tests being made at each temperature. It is also the intention to run, on these three boilers, about eight tests at temperatures of 1 800°, 2 100° and 2 400° Fahr., respectively. A bulletin on the work already done, together with much incidental matter, is in course of preparation.

*The assumption is made that a metal tube free from scale will remain almost as cool as the water; actual measurements with thermo-couples have indicated the correctness of this assumption in the majority of cases.

FIG. 1.—GAS PRODUCER, ECONOMIZER AND WET SCRUBBER.

FIG. 2.—PRODUCER GAS: DRY SCRUBBER AND GAS HOLDER.

The work on the first three boilers is only a beginning; preparations are being made to test eight more multi-tubular boilers of various lengths and tube diameters, under similar conditions. Because of the experience already obtained, it will be necessary to make only eight tests at each initial air temperature.

When the work on multi-tubular boilers is completed, water-tube boilers will be taken up, for which a fairly complete outline has been prepared. This second or water-tube portion of the investigation is really of the greater scientific and commercial interest, but the multi-tubular boilers were investigated first because the mathematical treatment is much simpler.

Producer-Gas Tests.—The producer-gas plant at the Pittsburg testing station is in charge of Mr. Carl D. Smith, and has been installed for the purpose of testing low-grade fuel, bone coal, roof coal, mine refuse, and such material as is usually considered of little value, or even worthless for power purposes. The gas engine, gas producer, economizer, wet scrubber (Fig. 1, Plate LXII), and accessories, are in Building No. 13, and the dry scrubber, gas-holder, and water-cooling apparatus are immediately outside that building (Fig. 2, Plate LXII).

At present immense quantities of fuel are left at the mines, in the form of culm and slack, which, in quality, are much below the average output. Such fuel is considered of little or no value, chiefly because there is no apparatus in general use which can burn it to good advantage. The heat value of this fuel is often from 50 to 75% of that of the fuel marketed, and if not utilized, represents an immense waste of natural resources. Large quantities of low-grade fuel are also left in the mines, simply because present conditions do not warrant its extraction, and it is left in such a way that it will be very difficult, if not practically impossible, for future generations to take out such fuel when it will be at a premium. Again, there are large deposits of low-grade fuel in regions far remote from the sources of the present fuel supply, but where its successful and economic utilization would be a boon to the community and a material advantage to the country at large. The great importance of the successful utilization of low-grade fuel is obvious. Until within very recent years little had been accomplished along these lines, and there was little hope of ever being able to use these fuels successfully.

The development of the gas producer for the utilization of ordinary fuels, however, indicates that the successful utilization of practically

all low-grade fuel is well within the range of possibility. It is notable that, although all producer-gas tests at the Government testing stations, at St. Louis and Norfolk, were made in a type of producer designed primarily for a good grade of anthracite coal, the fuels tested included a wide range of bituminous coals and lignites, and even peat and bone coal, and that, in nearly every test, little serious difficulty was encountered in maintaining satisfactory operating conditions. It is interesting to note that in one test, a bone coal containing more than 45% of ash was easily handled in the producer, and that practically full load was maintained for the regulation test period of 50 hours.*

It is not expected that all the fuels tested will prove to be of immediate commercial value, but it is hoped that much light will be thrown on this important problem.

The equipment for this work consists of a single gas generator, rated at 150 h.p., and a three-cylinder, vertical gas engine of the same capacity. The producer is a Loomis-Pettibone, down-draft, made by the Power and Mining Machinery Company, of Cudahy, Wis., and is known as its "Type C" plant. The gas generator consists of a cylindrical shell, 6 ft. in diameter, carefully lined with fire-brick, and having an internal diameter of approximately 4 ft. Near the bottom of the generator there is a fire-brick grate, on which the fuel bed rests. The fuel is charged at the top of the producer through a door (Fig. 1, Plate LXIII), which may be left open a considerable time without affecting the operation of the producer, thus enabling the operator to watch and control the fuel bed with little inconvenience. As the gas is generated, it passes downward through the hot fuel bed and through the fire-brick grate. This down-draft feature "fixes," or makes into permanent gases, the tarry vapors which are distilled from bituminous coal when it is first charged into the producer. A motor-driven exhauster with a capacity of 375 cu. ft. per min., draws the hot gas from the base of the producer through an economizer, where the sensible heat of the gas is used to pre-heat the air and to form the water vapor necessary for the operation of the producer. The pre-heated air and vapor leave the economizer and enter the producer through a passageway near the top and above the fuel bed. From the economizer the gas is drawn

* A report of these tests may be found in Bulletin No. * * * , U. S. Geological Survey.

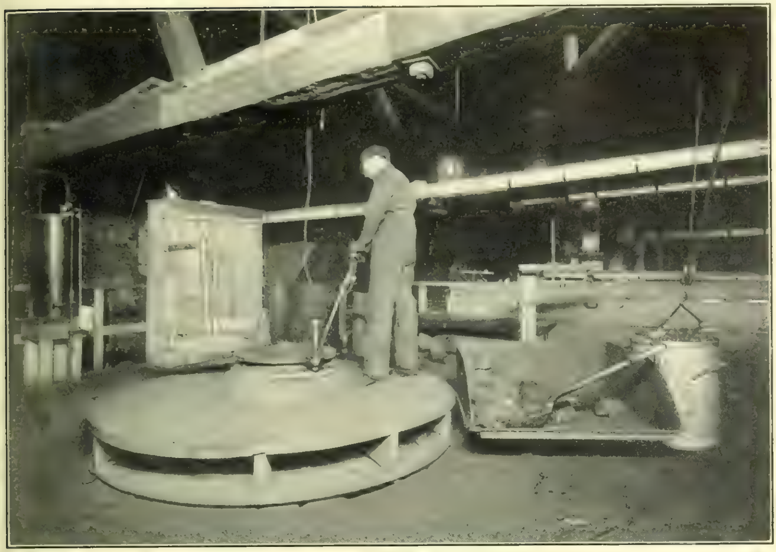


FIG. 1.—CHARGING FLOOR OF GAS PRODUCER.

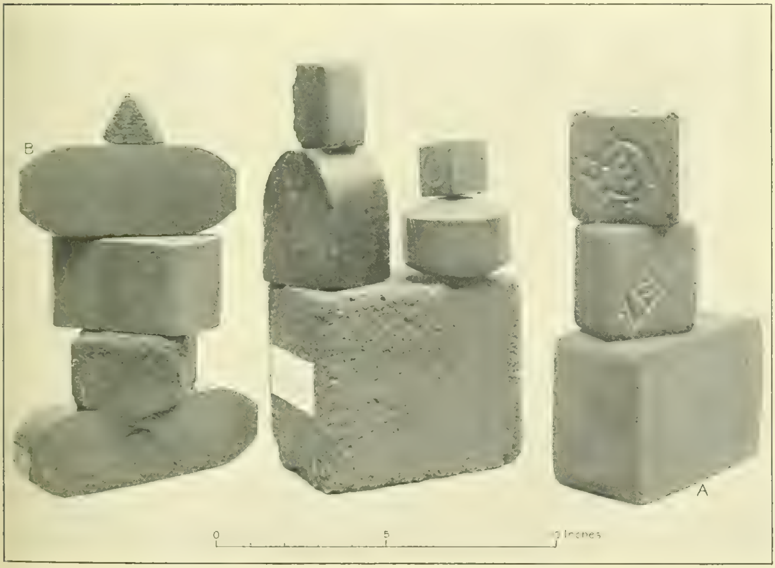


FIG. 2.—EUROPEAN AND AMERICAN BRIQUETTES.

through a wet scrubber where it undergoes a further cooling and is cleansed of dirt and dust. After passing the wet scrubber the gas, under a light pressure, is forced, by the exhauster, through a dry scrubber to a gas-holder with a capacity of about 1 000 cu. ft.

All the fuel used is carefully weighed on scales which are checked from time to time by standard weights; and, as the fuel is charged into the producer, a sample is taken for chemical analysis and for the determination of its calorific power. The water required for the generation of the vapor is supplied from a small tank carefully graduated to pounds; this observation is made and recorded every hour. All the water used in the wet scrubber is measured by passing it through a piston-type water meter, which is calibrated from time to time to insure a fair degree of accuracy in the measurement. Provision is made for observing the pressure and temperature of the gas at various points; these are observed and recorded every hour.

From the holder the gas passes through a large meter to the vertical three-cylinder Westinghouse engine, which is connected by a belt to a 175-kw., direct-current generator. The load on the generator is measured by carefully calibrated switch-board instruments, and is regulated by a specially constructed water rheostat which stands in front of the building.

Careful notes are kept of the engine operation; the gas consumption and the load on the engine are observed and recorded every 20 min.; the quantity of jacket water used on the gas engine, and also its temperature entering and leaving the engine jackets, are recorded every hour. Indicator cards are taken every 2 hours. The work is continuous, and each day is divided into three shifts of 8 hours each; the length of a test, however, is determined very largely by the character and behavior of the fuel used.

A preliminary study of the relative efficiency of the coals found in different portions of the United States, as producers of illuminating gas, has been nearly completed under the direction of Mr. Alfred H. White, and a bulletin setting forth the results is in press.

Tests of Liquid Fuels.—Tests of liquid fuels in internal-combustion engines, in charge of Mr. R. M. Strong, are conducted in the engine-room of Building No. 13.

The various liquid hydro-carbon fuels used in internal-combustion engines for producing power, range from the light refined oils, such as

naphtha, to the crude petroleums, and have a correspondingly wide variation of physical and chemical properties.

The most satisfactory of the liquid fuels for use in internal-combustion engines, are alcohol and the light refined hydro-carbon oils, such as gasoline. These fuels, however, are the most expensive in commercial use, even when consumed with the highest practical efficiency, which, it is thought, has already been attained, as far as present types of engines are concerned.

At present little is known as to how far many of the very cheap distillates and crude petroleums can be used as fuel for internal-combustion engines. It is difficult to use them at all, regardless of efficiency.

Gasoline is comparatively constant in quality, and can be used with equal efficiency in any gasoline engine of the better grade. There are many makes of high-grade gasoline engines, tests on any of which may be taken as representative of the performance and action of gasoline in an internal-combustion engine, if the conditions under which the tests were made are clearly stated and are similar.

Kerosene varies widely in quality, and requires special devices for its use, but is a little cheaper than gasoline. It is possible that the kerosene engine may be developed so as to permit it to take the place of the smaller stationary and marine gasoline engines. This would mean considerable saving in fuel cost to the small power user, who now finds the liquid-fuel internal-combustion engine of commercial advantage. A number of engines at present on the market use kerosene; some use only the lighter grades and are at best comparatively less efficient than gasoline engines. All these engines have to be adjusted to the grade of oil to be used in order to get the best results.

Kerosene engines are of two general types: the external-vaporizer type, in which the fuel is vaporized and mixed with air before or as it is taken into the cylinder; and the internal-vaporizer type, in which the liquid fuel is forced into the cylinder and vaporized by contact with the hot gases or heated walls of a combustion chamber at the head of the cylinder. A number of special devices for vaporizing kerosene and the lighter distillates have been tried and used with some success. Heat is necessary to vaporize the kerosene as quickly as it is required, and the degree of heat must be held between the temperature of vaporization and that at which the oil will be carbon-

ized. The vapor must also be thoroughly and uniformly mixed with air in order to obtain complete combustion. As yet, no reliable data on these limiting temperatures for kerosene and similar oils have been obtained. No investigation has ever been made of possible methods for preventing the oils from carbonizing at the higher temperatures, and the properties of explosive mixtures of oil vapors and air have not been studied. This field of engineering laboratory research is of vital importance to the solution of the kerosene-engine problem.

Distillates or fuel oils and the crude oils are much the cheapest of the liquid fuels, and if used efficiently in internal-combustion engines would be by far the cheapest fuels available in many large districts.

Several engine builders are developing kerosene vaporizers, which are built as a part of the engine, or are adapted to each different engine, as required to obtain the best results. Most of these vaporizers use the heat and the exhaust gases to vaporize the fuel, but they differ greatly in construction; some are of the retort type, and others are of the float-feed carburetter type. To what extent the lower-grade fuel oils can be used with these vaporizers is yet to be determined.

There are only a few successful oil engines on the American market. The most prominent of these represent specific applications of the principal methods of internal vaporization, and all except one are of the hot-bulb ignition type. It will probably be found that no one of the 4-stroke cycle, or 2-stroke cycle, engines is best for all grades of oil, but rather that each is best for some one grade. The Diesel engine is in a class by itself, its cycle and method of control being somewhat different from the others.

An investigation of the comparative adaptability of gasoline and alcohol to use in internal-combustion engines, consisting of more than 2 000 tests, was made at the temporary fuel-testing plant of the Geological Survey, at Norfolk, Va., in 1907. A detailed report of these tests is in preparation. A similar investigation of the comparative adaptability of kerosenes has been commenced, with a view to obtaining data on their economical use, leading up to the investigation of the comparative fuel values of the cheaper distillates and crude petroleum, as before discussed.

Washing and Coking Tests.—The investigations relating to the

preparation of low-grade coals, such as those high in ash or sulphur, by processes that will give them a higher market value or increase their efficiency in use, are in charge of Mr. A. W. Belden. They include the washing and coking tests of coals, and the briquetting of slack and low-grade coal and culm-bank refuse so as to adapt these fuels for combustion in furnaces, etc.

This work has been conducted in the washery and coking plant temporarily located at Denver, Colo., and in Building No. 32 at the Pittsburg testing station, where briquetting is in progress. The details of these tests are set forth in the various bulletins issued by the Geological Survey.

The washing tests are carried out in the following manner: As the raw coal is received at the plant, it is shoveled from the railroad cars to the hopper scale, and weighed. It then passes through the tooth-roll crusher, where the lumps are broken down to a maximum size of 2½ in. An apron conveyor delivers the coal to an elevator which raises it to one of the storage bins. As the coal is being elevated, an average sample representing the whole shipment is taken. An analysis is made of this sample of raw coal and float-and-sink tests are run to determine the size to which it is necessary to crush before washing, and the percentage of refuse with the best separation. From the data thus obtained, the washing machines are adjusted so that the washing test is made with full knowledge of the separations possible under varying percentages of refuse. The raw coal is drawn from the bin and delivered to a corrugated-roll disintegrator, where it is crushed to the size found most suitable, and is then delivered by the raw-coal elevator to another storage bin. The arrangement of the plant is such that the coal may be first washed on a Stewart jig, and the refuse then delivered to and re-washed on a special jig, or the refuse may be re-crushed and then re-washed.

When the coal is to be washed, it drops to the sluice box, where it is mixed with the water and sluiced to the jigs. In drawing off the washed coal, or when the uncrushed raw coal is to be drawn from a bin and crushed for the washing tests, however, a gate just below the coal-flow regulating gate is thrown in, and the coal falls into a central hopper instead of into the sluice box. Ordinarily, this gate forms one side of the vertical chute. The coal in this central hopper is carried by a chute to the apron conveyor, and thence to the roll

disintegrator, or, in case it is washed coal, to a swing-hammer crusher. It will be noted that coal, in this manner, can be drawn from a bin at the same time that coal is being taken from another bin, and sluiced to the jigs for washing, the two operations not interfering in the least.

The washed coal, after being crushed and elevated to the top of the building, is conveyed by a chute to the coke-oven larry, and is weighed on the track scale, after which it is charged to the oven. The refuse is sampled and weighed as it is wheeled to the dump pile, and from this sample the analysis is made and a float-and-sink test run to determine the "loss of good coal" in the refuse and to show the efficiency of the washing test.

The coking tests have been conducted in a battery of two beehive ovens, one 7 ft. high and 12 ft. in diameter, the other, 6¼ ft. high and 12 ft. in diameter. A standard larry with a capacity of 8 tons, and the necessary scales for weighing accurately the coal charged and coke produced, complete the equipment. The coal is usually run through a roll crusher which breaks it to about ½-in. size, or through a Pennsylvania hammer crusher. The fineness of the coals put through the hammer crusher varies somewhat, but the average, taken from a large number of samples, is as follows: Through ⅛-in. mesh, 100%; over 10-mesh, 31.43%; over 20-mesh, 24.29%; over 40-mesh, 22.86%; over 60-mesh, 10 per cent. The results of the coking tests are set forth in detail in the various publications issued on this subject.*

Tests of coke produced in the illuminating-gas investigations before referred to, and a study of commercial coking and by-product plants, are included in these investigations.

Briquetting Investigations.—These investigations are in charge of Mr. C. L. Wright, and are conducted in Building No. 32, which is of fire-proof construction, having a steel-skeleton frame work, reinforced-concrete floors, and 2-in. cement curtain walls, plastered on expanded-metal laths. In this building two briquetting machines are installed, one an English machine of the Johnson type, and the other a German lignite machine of very powerful construction.

The investigations include the possibility of making satisfactory commercial fuels from lignite or low-grade coals which do not stand

* U. S. Geological Survey, Professional Paper No. 48, Pt. III, and Bulletins Nos. 290, 332, 336, 368, 385, and 403.

shipment well, the benefiting of culm or slack coals which are wasted or sold at unremunerative prices, and the possibility of improving the efficiency of good coals. Some of the various forms of commercial briquettes, American and foreign, are shown in Fig. 2, Plate LXIII. After undergoing chemical analysis, the coal is elevated and fed to a storage bin, whence it is drawn through a chute to a hopper on the weighing scales. There it is mixed with varying percentages of different kinds of binding material, and the tests are conducted so as to ascertain the most suitable binder for each kind of fuel, which will produce the most durable and weather-proof briquette at least cost, and the minimum quantity necessary to produce a good, firm briquette. After weighing, the materials to be tested are run through the necessary grinding and pulverizing machines and are fed into the briquetting machines, whence the manufactured briquettes are delivered for loading or storage. The materials to be used in the German machine are also dried and cooled again.

The briquettes made at this plant are then subjected to physical tests in order to determine their weathering qualities and their resistance to abrasion; extraction tests and chemical analyses are also made. Meanwhile other briquettes from the same lots are subjected to combustion tests for comparison with the same coal not briquetted. These tests are made in stationary boilers, in house-heating boilers, on locomotives, naval vessels, etc., and the results, both of the processes of manufacture, and of the tests, are published in various bulletins issued by the Geological Survey.

The equipment includes storage bins for the raw coal, scales for weighing, machines for crushing or cracking the pitch, grinders, crushers, and disintegrators for reducing the coal to the desired fineness, heating and mixing apparatus, presses and moulds for forming the briquettes, a Schulz drier, and a cooling apparatus.

There is a small experimental hand-briquetting press (Fig. 1, Plate LXIV) for making preliminary tests of the briquetting qualities of the various coals and lignites. With this it is easily possible to vary the pressure, heat, percentage, and kind of binder, so as to determine the best briquetting conditions for each fuel before subjecting it to large-scale commercial tests in the big briquetting machines.

This hand press will exert pressures up to 50 tons or 100 000 lb. per sq. in., on a plunger 3 in. in diameter. This plunger enters a mould,

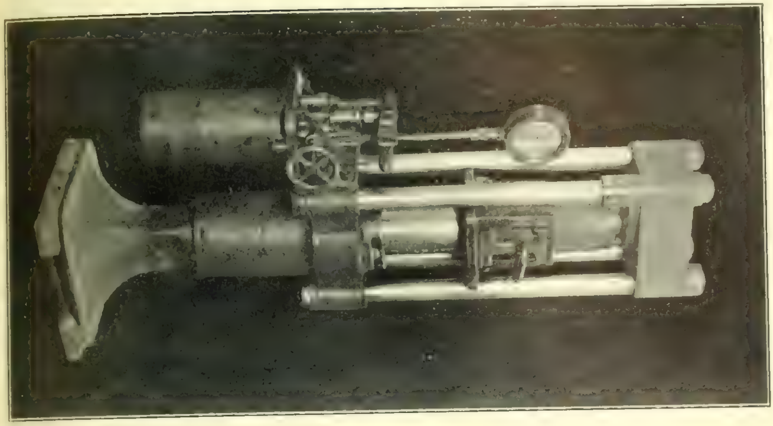


FIG. 1.—HAND BRIQUETTING PRESS.

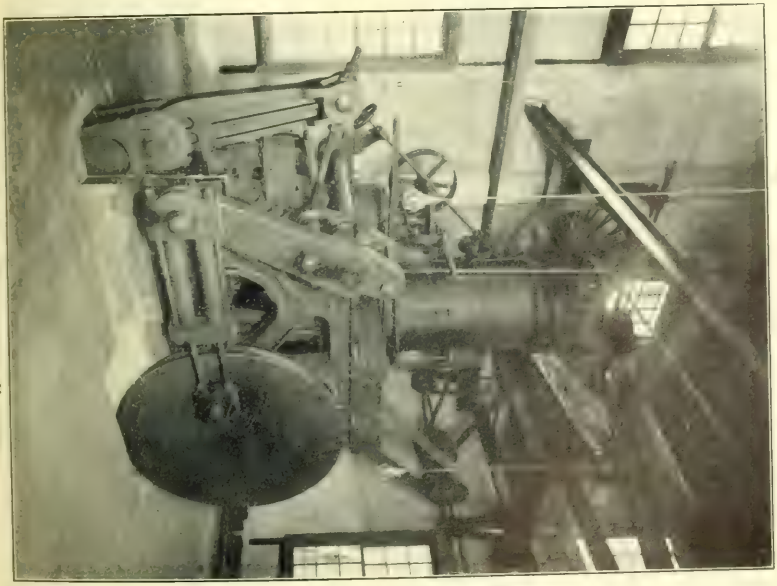


FIG. 2.—COAL BRIQUETTING MACHINE.

which can be heated by a steam jacket supplied with ordinary saturated steam at a pressure of 125 lb., and compresses the fuel into a briquette, 8 in. long, under the conditions of temperature and pressure desired.

The Johnson briquetting machine, which requires 25 h.p. for its operation, exerts a pressure of about 2 500 lb. per sq. in., and makes briquettes of rectangular form, $6\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ in., and having an average weight of about $3\frac{3}{4}$ lb. The capacity of the machine (Fig. 2, Plate LXIV) is about 3.8 tons of briquettes per 8-hour day.

Under the hopper on the scales for the raw material is a square wooden reciprocal plunger which pushes the fuel into a hole in the floor at a uniform rate. The pitch is added as uniformly as possible by hand, as the coal passes this hole. Under this hole a horizontal screw conveyor carries the fuel and pitch to the disintegrator, in front of which, in the feeding chute, there is a powerful magnet for picking out any pieces of iron which might enter the machine and cause trouble.

The ground mixture is elevated from the disintegrator to a point above the top of the upper mixer of the machine. At the base of this cylinder, steam can be admitted by several openings to heat the material to any desired temperature, usually from 180° to 205° Fahr. There, a plunger, making 17 strokes per min., compresses two briquettes at each stroke.

The German lignite-briquetting machine (Figs. 18 and 19) was made by the Maschinenfabrik Buckau Actien-Gesellschaft, Magdeburg, Germany. Lignite from the storage room on the third floor of the building is fed into one end of a Schulz tubular drier (Fig. 1, Plate LXV), which is similar to a multi-tubular boiler set at a slight angle from the horizontal, and slowly revolved by worm and wheel gearing, the lignite passing through the tubes and the steam being within the boiler. From this drier the lignite passes through a sorting sieve and crushing rolls to a cooling apparatus, which consists of four horizontal circular plates, about 13 ft. in diameter, over which the dried material is moved by rakes. After cooling, the material is carried by a long, worm conveyor to a large hopper over the briquette press, and by a feeding box to the press (Fig. 2, Plate LXV).

The press, which is of the open-mould type, consists of a ram and die plates, the latter being set so as to make a tube which grad-

ually tapers toward the delivery end of the machine. The briquettes have a cross-section similar to an ellipse with the ends slightly cut off; they are about 1¼ in. thick and average about 1 lb. in weight (Fig. 2, Plate LXIII). The press is operated by a direct connection with a steam engine of 150 h.p., the base of which is continuous with that of the press. The exhaust steam from the engine is used to heat the driver.

The plunger makes from 80 to 100 strokes per min., the pressure exerted ranging from 14 000 to 28 000 lb. per sq. in., the capacity of the machine being 1 briquette per stroke, or from 2½ to 3 tons of completed briquettes per hour. It is expected that no binder will be needed for practically all the brown lignite briquetted by this machine, thus reducing the cost as compared with the briquetting of coals, which require from 5 to 7% of water-gas, pitch binder costing more than 50 cents per ton of manufactured briquettes.

Peat Investigations.—Investigations into the distribution, production, origin, nature, and uses of peat are being conducted by Mr. C. A. Davis, and include co-operative arrangements with State Geological Surveys and the Geologic Branch of the U. S. Geological Survey. These organizations conduct surveys which include the mapping of the peat deposits in the field, the determination of their extent and limitations, the sampling of peat from various depths, and the transmittal of samples to the Pittsburg laboratories for analysis and test.

This work is co-ordinated in such a manner as to result in uniform methods of procedure in studying the peat deposits of the United States. The samples of peat are subjected to microscopic examination, in order to determine their origin and age, and to chemical and physical tests at the laboratories in Pittsburg, so as to ascertain the chemical composition and calorific value, the resistance to compressive strains, the ash and moisture content, drying properties, resistance to abrasion, etc. Occasionally, large quantities of peat are disintegrated and machined, and portions, after drying for different periods, are subjected to combustion tests in steam boilers and to tests in the gas producer, to ascertain their efficiency as power producers.

Results.—The full value of such investigations as have been described in the preceding pages cannot be realized for many years; but, even within the four years during which this work has been under way, certain investigations have led to important results, some of which may be briefly mentioned:

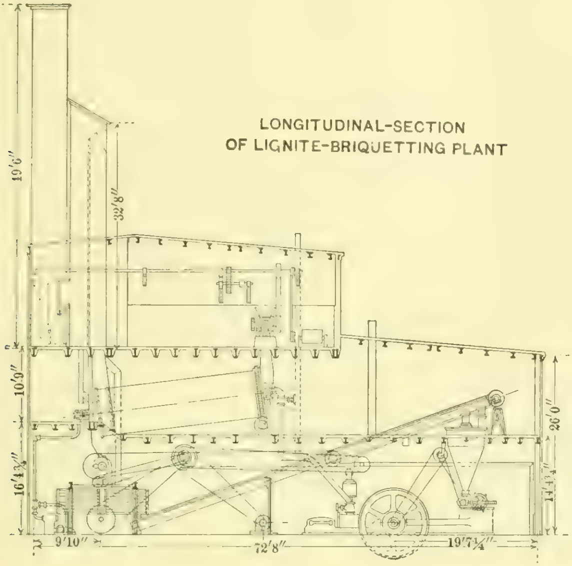

LONGITUDINAL-SECTION
OF LIGNITE-BRIQUETTING PLANT
19'6"
32'8"
10'9"
16'4¾"
26'0"
14'4¾"
9'10"
72'8"
19'7¼"

FIG. 18.

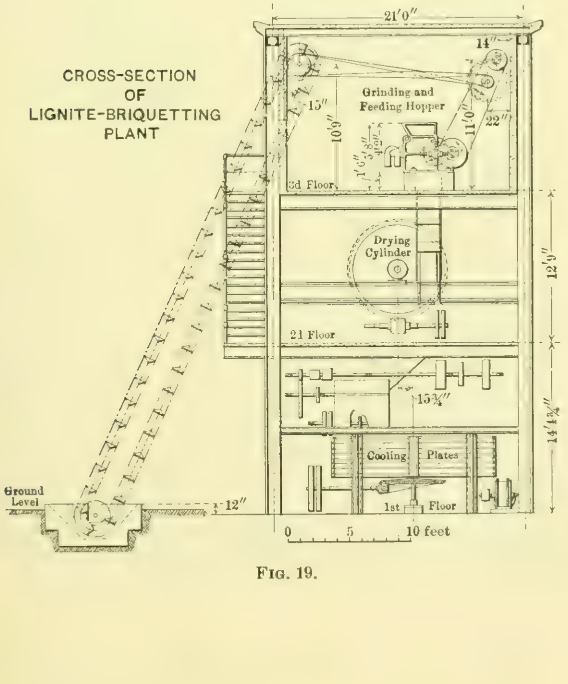

CROSS-SECTION
OF
LIGNITE-BRIQUETTING
PLANT
21'0"
14"
15"
Grinding and
Feeding Hopper
10'9"
11'0"
22"
3d Floor
Drying
Cylinder
12'9"
2d Floor
15¾"
14'4¾"
Cooling
Plates
1st
Floor
Ground
Level
12"
0
5
10 feet

FIG. 19.

The chemical and calorific determinations of coals purchased for the use of the Government have resulted in the delivery of a better grade of fuel without corresponding increase in cost, and, consequently, in saving to the Government. Under this system, of purchasing its coal under specifications and testing, the Government is getting more nearly what it pays for and paying for what it gets. These investigations, by suggesting changes in equipment and methods, are also indicating the practicability of the purchase of cheaper fuels, such as bituminous coal and the smaller sizes of pea, buckwheat, etc., instead of the more expensive sizes of anthracite, with a corresponding saving in cost. The Government's fuel bill now aggregates about $10 000 000 yearly.

The making and assembling of chemical analyses and calorific determinations (checked by other tests) of carefully selected samples of coals from nearly 1 000 different localities, in the different coal fields of the United States, with the additions, from time to time, of samples representing parts of coal fields or newly opened beds of coal in the same field, furnish invaluable sources of accurate information, not only for use of the Government, but also for the general public. Of the above-mentioned localities, 501 were in the public-land States and 427 in the Central, Eastern, and Southern States.

The chemical anaylses of the coals found throughout the United States have been made with such uniformity of method, both as to collection of samples and analytical procedure, as to yield results strictly comparable for coals from all parts of the country, and furnish complete information, as a basis for future purchases and use by the Government and by the general public, of all types of American coals.

Other researches have resulted in the acquirement of valuable information regarding the distribution of temperature in the fuel bed of gas producers and furnaces, showing a range of from 400° to 1 300° cent., and have thus furnished data indicating specific difficulties to be overcome in gas-producer improvements for greater fuel efficiency.

The recent studies of the volatile matter in coal, and its relation to the operation of coke ovens and other forms of combustion, have demonstrated that as much as one-third of this matter is inert and non-combustible, a fact which may have a direct bearing on smoke prevention by explaining its cause and indicating means for its abatement.

FIG. 1.—DRYER FOR LIGNITE BRIQUETTING PRESS.

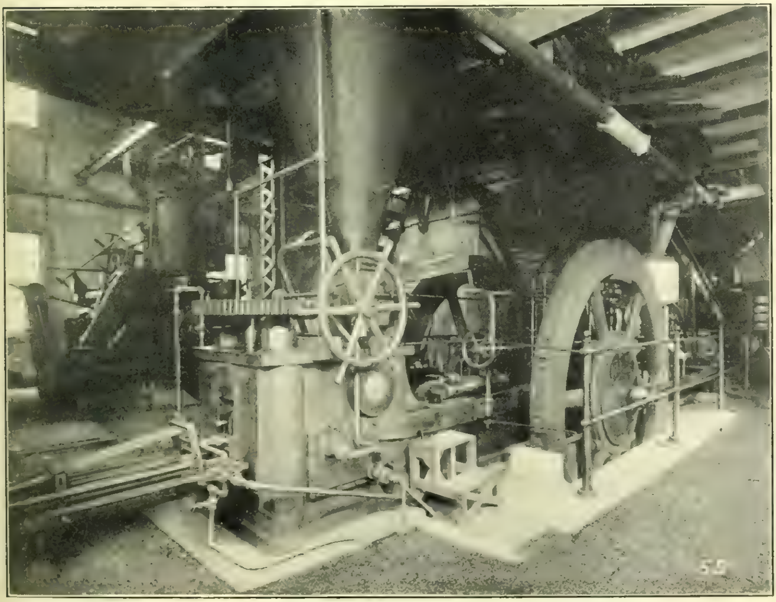


FIG. 2.—LIGNITE BRIQUETTING MACHINE.

Experiments in the storage of coal have proven that oxygen is absorbed during exposure to air, thereby causing, in some cases, a deterioration in heating value and indicating that, for certain coals, in case they are to be stored a long time for naval and other purposes, storage under water is advisable.

The tests of different coals under steam boilers have shown the possibility of increasing the general efficiency of hand-fired steam boilers from 10 to 15% over ordinary results. If this saving could be made in the great number of hand-fired boilers now being operated in all parts of the United States, it would result in large saving in the fuel bill of the country. Experiments which have been made with residence-heating boilers justify the belief that it will be possible to perfect such types of boilers as may economically give a smokeless operation. The tests under steam boilers furnish specific information as to the most efficient method of utilizing each of a number of different types of coal in Government buildings and power plants in different parts of the country.

The tests in the gas producer have shown that many fuels of such low grade as to be practically valueless for steam-furnace purposes, including slack coal, bone coal, and lignite, may be economically converted into producer gas, and may thus generate sufficient power to render them of high commercial value.

Practically every shipment out of several hundred tested in the gas producers, including coals as high in ash content as 45%, and lignites and peats high in moisture, has been successfully converted into producer gas which has been used in operating gas engines. It has been estimated that on an average there was developed from each coal tested in the gas-producer plant two and one-half times the power developed when used in the ordinary steam-boiler plant, and that such relative efficiencies will probably hold good for the average plant of moderate power capacity, though this ratio may be greatly reduced in large steam plants of the most modern type. It was found that the low-grade lignites of North Dakota developed as much power, when converted into producer gas, as did the best West Virginia bituminous coals when utilized under the steam boiler; and, in this way, lignite beds underlying from 20 000 000 to 30 000 000 acres of public lands, supposed to have little or no commercial value, are shown to have a large value for power development.

The tests made with reference to the manufacture and combustion of briquetted coal have demonstrated conclusively that by this means many low-grade bituminous coals and lignites may have their commercial value increased to an extent which more than covers the increased cost of making; and these tests have also shown that bituminous coals of the higher grades may be burned in locomotives with greatly increased efficiency and capacity and with less smoke than the same coal not briquetted. These tests have shown that, with the same fuel consumption of briquettes as of raw coal, the same locomotive can very materially increase its hauling capacity and thus reduce the cost of transportation.

The investigations into smoke abatement have indicated clearly that each type of coal may be burned practically without smoke in some type of furnace or with some arrangement of mechanical stoker, draft, etc. The elimination of smoke means more complete combustion of the fuel, and consequently less waste and higher efficiency.

The investigations into the waste of coal in mining have shown the enormous extent of this waste, aggregating probably from 300 000 000 to 400 000 000 tons yearly, of which at least one-half might be saved. It is being demonstrated that the low-grade coals, high in sulphur and ash, now left underground, can be used economically in the gas producer for power and light, and, therefore, should be mined at the same time that the high-grade coal is being removed. Moreover, attention is now being called to the practicability of a further large reduction of waste through more efficient mining methods.

The washing tests have demonstrated the fact that many coals, too high in ash and sulphur for economic use under the steam boiler or for coking, may be rendered of commercial value by proper treatment in the washery. The coking tests have also demonstrated that, by proper methods of preparation for and manipulation in the beehive oven, many coals which were not supposed to be of economic value for coking purposes, may be rendered so by prior washing and proper treatment. Of more than 100 coals tested during 1906 from the Mississippi Valley and the Eastern States, most of which coals were regarded as non-coking, all except 6 were found, by careful manipulation, to make fairly good coke for foundry and other metallurgical purposes. Of 37 coals from the Rocky Mountain region, all but 3

produced good coke under proper treatment, though a number of these had been considered non-coking coals.

Investigations into the relative efficiency of gasoline and denatured alcohol as power producers, undertaken in connection with work for the Navy Department, have demonstrated that with proper manipulation of the carburetters, igniters, degree of compression, etc., denatured alcohol has the same power-producing value, gallon for gallon, as gasoline. This is a most interesting development, in view of the fact that the heat value of a gallon of alcohol is only a little more than 0.6 that of a gallon of gasoline. To secure these results, compressions of from 150 to 180 lb. per sq. in. were used, these pressures involving an increase in weight of engine. Although the engine especially designed for alcohol will be heavier than a gasoline engine of the same size, it will have a sufficiently greater power capacity so that the weight per horse-power need not be greater.

Several hundred tons of peat have been tested to determine methods of drying, compressing into briquettes, and utilization for power production in the gas producer. In connection with those peat investigations, a reconnoissance survey has been made of the peat deposits of the Atlantic Coast. Samples have been obtained by boring to different depths in many widely distributed peat-bogs, and these samples have been analyzed and tested in order to determine their origin, nature, and fuel value.

The extent and number of tests from which these results have been derived will be appreciated from the fact that, in three years, nearly 15 000 tests were made, in each of which large quantities of fuel were consumed. These tests involved nearly 1 250 000 physical observations and 67 080 chemical determinations, made with a view to analyze the results of the tests and to indicate any necessary changes in the methods as they progressed. For coking, cupola, and washing, 596 tests, of which nearly 300 involved the use of nearly 1 000 tons of coal, have been made at Denver. For briquetting, 312 tests have been made. Briquettes have been used in combustion tests in which 250 tons of briquetted coal were consumed in battleship tests, 210 tons in torpedo-boat tests, 320 tons in locomotive tests on three railway systems, and 70 tons were consumed under stationary steam boilers. Of producer gas tests, 175 have been made, of which 7 were long-time runs of a week or more in duration, consuming in all 105

tons of coal. There have been 300 house-heating boiler tests and 575 steam-boiler tests; also, 83 railway-locomotive and 23 naval-vessel tests have been made on run-of-mine coal in comparison with briquetted coal; also, 125 tests have been made in connection with heat-transmission experiments, and 2 254 gasoline- and alcohol-engine tests. Nearly 7 000 samples of coal were taken for analysis, of which 1 042 were from public-land States. Nearly 3 400 inspection samples, of coal purchased by the Government for its use, have been taken and tested.

The results of the tests made in the course of these investigations, as summarized, have been published in twelve separate Bulletins, three of which, Nos. 261, 290, and 332, set forth in detail the operations of the fuel-testing plant for 1904, 1905, and 1906. Professional Paper No. 48, in three volumes, describes in greater detail each stage of the operations for 1904 and 1905.

Separate Bulletins, descriptive of the methods and results of the work in detail, have been published, as follows: No. 323, Experimental work conducted in the chemical laboratory; No. 325, A study of four hundred steaming tests; No. 334, Burning of coal without smoke in boiler plants; No. 336, Washing and coking tests of coal, and cupola tests of coke; No. 339, Purchase of coal under specifications on basis of heating value; No. 343, Binders for coal briquettes; No. 362, Mine sampling and chemical analyses of coals in 1907; No. 363, Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests, and some foreign specifications for briquetted fuel; No. 366, Tests of coal and briquettes as fuel for house-heating boilers; No. 367, Significance of drafts in steam-boiler practice; No. 368, Coking and washing tests of coal at Denver; No. 373, Smokeless combustion of coal in boiler plants, with a chapter on central heating plants; No. 378, Results of purchasing coal under Government specifications; No. 382, The effect of oxygen in coal; and, No. 385, Briquetting tests at Norfolk, Va.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

UNDERPINNING THE CAMBRIDGE BUILDING, NEW YORK CITY.

Discussion.*

By Henry Gorton Opdycke, Assoc. M. Am. Soc. C. E.

Henry Gorton Opdycke, Assoc. M. Am. Soc. C. E.—In connection with Mr. Thomson's paper the speaker simply desires to emphasize a point or two therein, and to call attention to the necessity of engaging competent engineers by owners of property adjoining operations of the character of this tunnel, before such operations have commenced. There are several reasons for this, the first of which is, that, by reason of the individual's more intimate knowledge of the conditions obtaining at his particular location, he is better able to forestall operations which will endanger his property, and it is important for the owner to lay the foundations for proper legal measures to recompense him for his possible damage; also, by consultation with the contractor's engineers, operations which may endanger his property may be prevented. Mr. Opdycke.

In the case in point, as far back as several weeks before the cave-in on Thirty-third Street opposite the Cambridge, the speaker notified the owner of the property of the impending danger. The owner did not appreciate the dangerous condition, however, until several weeks later, after the street had caved in at the very point designated as the bed of the old stream, although the contractor had placed much dependence on the location of this stream as shown on the Viele map, which indicated that it was about 100 ft. farther west.

*This discussion (of the paper by T. Kennard Thomson, M. Am. Soc. C. E., printed in *Proceedings* for December, 1909, and presented at the meeting of February 2d, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

Mr. Opdycke.

In the speaker's reports to the owner, before the cave-in, it was recommended that the tunnel company be requested to lower the grade of the tunnel in order to escape this serious condition, but this was not acted on, and, after the cave-in, when the contractors asked for consent to continue their operations, this owner was in position to know his status and to require a contract, not only guaranteeing the integrity of his building, but its actual underpinning to bed-rock.

After the consent to continue operations had been obtained from this owner, the tunnel company concluded to lower the level of the tunnel, and this was finally done.

By reason of this first cave-in, together with the effect of the misdirected blast under the foundations of the Cambridge Building, mentioned by Mr. Thomson and shown on Fig. 1, the front wall of the building commenced to settle and move northward toward the center of the street. It was then that photographs were taken for the purpose of preserving legal evidence of the facts.

The speaker may state that the conditions predicted to the owner were entirely fulfilled, and the lessee of the building, who, under his lease, was responsible to the owner, was enabled to recover a judgment in the Supreme Court for the full amount of his damage, together with the court costs.

The speaker desires to emphasize another phase of the situation at the Cambridge Building, and that is the likelihood that such structures as this tunnel will reduce the surrounding water level and provide a new channel for the escape of the water, thus leaving buildings in the vicinity which have been erected on piles subject to much damage from decayed piles.

As to the case in point, when the cellar of the Waldorf-Astoria (on the north side of Thirty-third Street and directly opposite the Cambridge Building) was being constructed, the owner's representatives remember very distinctly the presence of much water, apparently from this old stream, and also that a sump in the boiler pit, in the basement of the Cambridge, was continually filled with water until after the openings were made into the tunnel excavation.

Borings were made in the cellar of the Cambridge after the two openings were made into the tunnel, and an examination by the speaker developed the fact that the water had been entirely drained from the soil surrounding the piles, and down to bed-rock.

When, early in 1907, the speaker examined the interior of the tunnel, water was flowing into it through the opening in the rock where the street had caved in, and after this part of the tunnel was sealed off, and the water shut out, instead of again raising the water level in the surrounding soil, the conditions mentioned above maintained, that is, there was lack of water in the soil.

There seems to be but one explanation for this condition, and that

is that the water from the drainage area of this old stream still continues to flow along a new channel caused by the tunnel company's operations. Mr. Opdycke.

The speaker would call attention to another reason why property owners should be represented by engineers on an occasion such as this.

When the tunnel contractor saw fit to tie back the north wall of the Cambridge, he began operations by cutting a hole in the front wall of the building, in the middle of the principal office of one of the best tenants, at a point about 2½ ft. above the floor, the intention being to put a tie-rod through this office out into the main hall directly in front of the elevators, and across the main stairway, effectually obstructing them, or giving all the tenants the choice of crawling under or hurdling over the tie-rod.

This was unnecessary, as was demonstrated by the fact that tie-rods were finally put in with no permanent inconvenience to the tenants.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS AND DISCUSSIONS

BUILDING AGREEMENTS.

Discussion.*

By Messrs. Norman R. McLure, William V. Polleys, and Charles H. Higgins.

Mr. McLure. Norman R. McLure, Assoc. M. Am. Soc. C. E. (by letter).—In preparing estimates and bids on engineering work, chiefly in connection with the structural steel business, the writer has been continually confronted with the so-called "blanket clauses" in contracts and specifications. At first they were the cause of much anxiety, on account of the confusion and the uncertain element which they introduced, but later experience has proven them almost invariably an indication of ignorance or lack of understanding on the part of the engineer or architect responsible for their preparation.

In its most familiar form, such a clause follows an apparently mighty effort to cover everything with a statement that, if anything has been omitted from the plans or specifications which may be necessary "to make a complete and satisfactory job," or "to complete the work to the satisfaction of the architects," it is to be included in the bid, and constitute part of the contract; or, in other words, the writer of the specification practically says, "If I have omitted anything that I should have included, you (the contractor) must accept the responsibility for it." In addition to his business as a contractor, a bidder must also be a mind reader, or else practically start at the beginning and design the whole work, in order to ascertain whether the plans and data on which he is asked to bid, are complete.

* This discussion (of the paper by William B. Bamford, Assoc. M. Am. Soc. C. E., published in *Proceedings* for December, 1909, and presented at the meeting of February 2d, 1910), is published in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

It is obviously so unfair to solicit lump-sum bids on work not shown or specified, that instead of attempting to solve the riddle of what is really wanted, in cases of this sort, the writer now simply prepares his bid on the work clearly shown and specified, and states distinctly in the proposal, what is and what is not included. The basis for comparison of lump-sum bids prepared in this way, is, of course, unsatisfactory. Mr. McLure.

Architects seem to be the chief offenders, and, in the writer's experience, it is quite unusual to pick up a set of building plans and specifications prepared by an architect, and be able to discover, without much inquiry and investigation, just what is wanted. Engineers, apparently, are more careful, and make some effort to decide in their own minds just what they want before attempting to put it on paper. There is, however, infinite room for improvement in specification writing from the contractor's viewpoint; and as every structure has sufficient individuality to make it worthy of independent treatment, just so should every specification receive, in preparation, the intelligent thought of one who understands thoroughly the structure it describes.

"Standard" specifications, while useful, and almost indispensable as guides, should be used in that capacity only, and the representative contract clauses given by the author should prove, in that way, of great value in preparing any ordinary building contract.

William V. Polleys, M. Am. Soc. C. E. (by letter).—The writer respectfully begs to take most decided exception to Mr. Bamford's statement that the lump-sum system of contracting is theoretically or practically the best, even in straight building operations where no unusual complications occur, and, further, he ventures the opinion that there are comparatively few building operations (of sufficient importance to justify a discussion before this Society) in which unforeseen complications to a greater or less extent do not arise. Mr. Polleys.

With regard to Mr. Bamford's statement that the expense of work done by reputable "cost plus" contractors generally exceeds the cost under a lump-sum agreement covering identical work, because the owner is ill-advised or because the contractor, being sure of his profit, grows lax, or from any other cause, the writer desires to state that such has not been his experience, nor does he believe that such a statement is borne out by facts, nor by the experience of most men who have had intimate connection with both methods of work.

Getting ready for bids for lump-sum work is, in itself, a tedious and expensive operation, plans and specifications must be prepared providing for all contingencies which can be foreseen, but the usual result is that something has been overlooked or that the unexpected has happened.

Generally speaking, in the larger and more intelligently handled building operations, weight is given, in selecting the list of competi-

Mr. Polleys. tors, to their financial standing and to their reputation for experience and ability, but the competitors, nevertheless, are asked to gamble on the price of labor, material, on the state of the weather, on the state of mind of the person in charge, and on countless other matters entirely beyond their control, for a period of months, or possibly years, in advance.

The multitudinous clauses of the modern contract are to insure against human nature asserting itself if things go wrong. If things go as expected, or better, the builder, remembering that money is a good thing anyway, that his next bet may not be so fortunate, and that the owner, in endeavoring to tie him up, evidently expects him to untie himself if he can, proceeds to make every dollar possible under the circumstances, influenced, of course, by the desire to retain a good reputation, if it is not too expensive.

As long as the interests of owners and builders are thus diametrically opposed, the result is quite likely to be injurious to the operation in question, and, until human nature is greatly changed, will continue to be so, in spite of all the legal acumen that may be injected into a contract.

In the writer's opinion, the only remedy is to unite these clashing interests by some form of a "cost plus" contract. Under this arrangement the interests of the owner and the builder are identical as far as possible.

The owner has merely to select some such contractor of known skill and reputation, tell him what he wants, ascertain the probable cost, with due allowance for unforeseen contingencies, and, if this is satisfactory, order the work to proceed.

He will get just what he orders and pays for, and will get it as cheaply, as quickly, and done as skillfully, as it can be obtained by any contract; not because the "cost plus" contractor is cast in a different mould from his "lump sum" brother, but because his whole stock in trade is his reputation, and because his interests and those of the owners have become identical.

His employees are as skillful as any, have every incentive to do just the class of work that the owner wants, and to do it as cheaply as it can be done.

If the employee of a "lump sum" contractor is careless or makes a mistake, it means the loss of a comparatively small sum of money, which is not of very great consequence; but, in the case of the "cost plus" contractor, it means a blow at his reputation which endangers his entire capital.

Dealing with reputable contractors who make a specialty of "cost plus" work, it makes no practical difference whether the "plus" be a percentage or a lump sum. Any difference in profit is too small to overcome in the slightest degree the overwhelming necessity on the part of the contractor to maintain an unblemished reputation.

The simpler the contract the better, any attempt to penalize or augment what should be but a fair compensation in the first place, by reason of variations from the estimate of cost or time, merely tends to divide the interests and invite the attendant evils. Mr. Polleys.

There are so many other advantages attending the "cost plus" method of building that to emphasize them as they deserve exceeds the length intended for these remarks. Among them, however, there are: the expert advice available, both technical and business; elimination of pooling; the saving of time, in that work may be started as soon as a general plan has been formulated, leaving details to be worked out during progress; the fact that work may be advanced, retarded, suspended, or even abandoned, as exigencies may demand; plans may be changed; quantities may be increased or diminished; and all without that formidable bill of extras and damages, which is the "right bower" of the lump-sum contractor, and a disastrous weight to many owners.

It has been truly said that the bulwark of a contract is mutual confidence, and it may be added that the bulwark of mutual confidence is mutual interests.

CHARLES H. HIGGINS, ASSOC. M. AM. SOC. C. E. (by letter).—Mr. Bamford's able paper opens first of all the question of the desirability of a uniform contract, a subject which the American Institute of Architects has attempted in what is called the "Uniform Contract," but which, as far as the writer knows, has not been met by engineers, through this Society or otherwise, except in railroad contracts which agree in their general characteristics. Fairness is not the most striking feature of the latter, and they are not well adapted to the use of the consulting engineer in general practice, to which class, together with architects, the word, "Engineer," in Mr. Bamford's paper, seems to refer. Mr. Higgins.

It may be accepted as axiomatic that "unfair contracts breed unfair contractors"—a case of the survival of the fittest.

It is desirable for all parties—the owner, the contractor, and the engineer—that the contract be fair, that contracting may be a business in the hands of responsible men rather than a game for gamblers.

Uniformity in the general clauses has a great advantage in itself, most directly to the contractor, but, through him, to all concerned. Imagine each engineer with a pet form of contract, all equally good, but differing in degree of responsibility, which necessarily affects the cost—an effect which may not be large relative to the total cost of the work, but is very large relative to the profit of the general contractor. This means that, in bidding on each piece of work, the contractor must study, not only the proposed construction in which he is an expert, but also the legal requirements, thus adding materially to the time and cost of making a proposal and reducing the number of

Mr. Higgins. close bidders. Of course, uniformity can be carried to the point of absurdity. A certain printed form of contract, recently signed, required the contractor to deliver a full-sized sample of each of the materials entering into the work at the architect's office before commencing operations. The "office" was a modern New York affair, well up in the air, and the contract was for driving 50-ft. piles. Here, clearly, the written words did not convey the intent of the contracting parties. There was not a "meeting of the minds," which constitutes a contract; and here is an advantage of certain general clauses in common use, which is what Mr. Bamford aims at. These clauses, of course, must conform with the law, and might differ slightly for use in different States; but, in the main, if such a uniform contract met with general acceptance, this fact and the usual manner of interpreting the clauses would be presumptive evidence of the intent, and thus influence the decisions of the courts, and further strengthening such a form of contract. A judge—and how much more so a jury—must be puzzled as to the intent when technical questions are involved and the parties to the contract cannot agree as to the meaning.

Of course, the defence of such a form of contract as is used by many railroad companies, drawn as it is almost wholly in the interest of one side, is that if the case gets before a jury, the talesmen's sympathies will be all on the side of the contractor as against the corporation, and, therefore, every effort must be made to keep it from a jury; but, if this be valid reasoning in the case of a railroad with a coterie of more or less dependent contractors, all familiar with the requirements and, what is more important, with the way the requirements are exacted, it does not by any means hold in the case of general building contracts carried out under an engineer.

"*Article I.*—The Contractor agrees to provide all materials and perform all the work for the * * *."

The writer would suggest adding in the foregoing, after the word "work," "and deliver complete," thus making the contract for a completed structure rather than for the furnishing of materials and labor. Decisions of the courts would seem to indicate the wisdom of this.

Perhaps first in importance is the arbitration clause, with all its legal pitfalls, and the possible requirement for better legislation which Mr. Bamford refers to, and which Wait treats so fully in his "Engineering and Architectural Jurisprudence," for this fixes the responsibility of the engineer, whether his decision is to be supreme until the matter is taken before the courts, or whether he can say, "This, gentlemen, is my decision; if either of you feels aggrieved, you have the privilege of calling in arbitrators." This would seem to be the strongest position for the engineer, for the owner is not always inclined to follow the advice of his engineer, and is often unfair be-

cause he is not thoroughly acquainted with the subject. The fact, stated by J. A. L. Waddell, M. Am. Soc. C. E., in "Specifications and Contracts", that "the law has decided that the losing party has still a right to appeal to the courts", should not be lost sight of. The courts seem to be jealous of their privileges in these matters. Mr. Higgins.

Liquidated Damages.—This clause is a "thorn in the flesh" to a contractor, and yet it is often of the utmost importance to the owner that he shall know beforehand when he will receive the completed structure. The law will not allow a penalty, but will grant damages caused by delay. To the writer it seems wisest to state that time of completion is a consideration, and have the bidder name a time with his price. Then, before the contract is signed, have the owner and the contractor agree as to the amount per diem which the damage to the owner will amount to, in case of delay by the contractor. This should be written into the contract, with provision for retaining the sum from monies due.

Drawings.—Under this head it would seem well to provide a time, say one week, which would be allowed the engineer for the examination and return of drawings, with the provision that if he takes longer, the contractor's time for completion shall be prolonged proportionately.

One of the chief advantages an owner receives by retaining an engineer is the benefit of open and fair competition among contractors in the matter of price, and this is in direct proportion to the clearness and definiteness with which the subject for competition is presented. Therefore, it is the duty of engineers to work for all things which make for a more definite and fair relation between the owner, represented by his engineer, and the contractor. The writer joins Mr. Bamford in his plea for the development, by this Society, of uniform contract clauses, after careful consideration, and with an arrangement for revisions as new legislation and decisions by the courts may require.

William P. Morse

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OF

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CONTENTS

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Vol. XXXVI. MARCH, 1910. No. 3.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PROCEEDINGS

SOCIETY AFFAIRS

CONTENTS

MINUTES OF MEETINGS

OF THE SOCIETY

February 16th, 1910.—The meeting was called to order at 8.30 P. M.; Vice-President George H. Pegram in the chair; T. J. McMinn, Assistant Secretary, acting as Secretary; and present, also, 148 members and 17 guests.

A paper by George Gray Anderson, M. Am. Soc. C. E., entitled "The Effect of Alkali on Concrete," was presented by the Assistant Secretary, and the subject was discussed by Messrs. Rudolph Hering, R. L. Humphrey, George F. Morse, M. R. Sherrerd, R. H. Gaines, and J. L. Davis. Written discussions from Messrs. Thomas H. Means, F. E. Robertson, R. A. Hart, and Philo H. Bates, were read by title.

A paper by John Hawkesworth, Assoc. M. Am. Soc. C. E., entitled "Precarious Expedients in Engineering Practice," was read by title, and discussed by E. W. Stern, M. Am. Soc. C. E. Written discussions from Messrs. W. W. Crosby, J. S. Branne, and Andrews Allen were read by title.

The Assistant Secretary announced the following deaths:

John Fiske Barnard, elected Member September 1st, 1880; died February 6th, 1910.

John Joseph Horan, elected Associate Member October 7th, 1908; died November 9th, 1909.

Henry Cyprian Humphrey, elected Associate Member September 4th, 1901; Member October 3d, 1905; died December 9th, 1909.

George Huntington Thomson, elected Member February 2d, 1887; died February 7th, 1910.

Adjourned.

March 2d, 1910.—The meeting was called to order at 8.30 p. m.; James Owen, M. Am. Soc. C. E., in the chair; T. J. McMinn, Assistant Secretary, acting as Secretary; and present, also, 140 members and 16 guests.

The minutes of the Annual Meeting, January 19th, and of the meeting of February 2d, 1910, were approved as printed in *Proceedings* for February, 1910.

The Assistant Secretary read the following letter from the Colorado Association of Members of the American Society of Civil Engineers:

"Denver, Colorado, February 15th, 1910.

"Mr. Charles Warren Hunt, Secretary,
"American Society of Civil Engineers,
"220 West 57th Street,
"New York.

"Dear Sir:—At the February meeting of our Association, a motion was presented and adopted to the effect that our Association take the initiative in asking the Society to appoint a standing committee on Wood Preservation.

"As none of our members are likely to attend any regular meeting of the Society in the near future, would be pleased to have you arrange for presenting the following motion or its equivalent at the next meeting of the Society:

"That the Board of Direction be requested to appoint a committee of nine to investigate and report on the 'Preservation of Wood.'

"Our argument supporting this motion is as follows:

"A committee of the Society was appointed for this purpose in 1880 and reported in 1885. Their report was at that time, and probably is still, the most comprehensive publication on the subject. Since 1885, there have been advances in the art of wood preservation. Many experiments have been made, but the data resulting from the experience and the experiments of the last twenty-five years have not been correlated and published in a way to make them available to engineers.

"Trusting that you will have this matter presented to the Society, and that it will result in the appointment of a committee, I am,

"Yours very truly,
"H. J. Burt,
"Secy.-Treas."

It was moved that a Special Committee be appointed (as provided for in Article VI, Section 12, of the Constitution) to investigate and report on the preservation of wood.

The motion, being duly seconded, was adopted by a vote of more than twenty-five Corporate Members.

A paper by John H. Gregory, M. Am. Soc. C. E., entitled "The Improved Water and Sewage Works of Columbus, Ohio," was presented by the author and illustrated with lantern slides.

The paper was discussed by Messrs. Alexander Potter, E. Kuichling, W. Gavin Taylor, Allen Hazen, and William B. Fuller. Written discussions from Messrs. Joseph W. Ellms, Julian Griggs, C.-E. A. Winslow, R. D. Scott and R. F. McDowell, Samuel Tobias Wagner, C. B. Hoover, and J. Corbett were read by title.

The Assistant Secretary announced the election of the following candidates by the Board of Direction on March 1st, 1910:

AS MEMBERS.

ALBERT MARSHALL BROSIUS, Baltimore, Md.
ABRAHAM BRUNER, Roanoke, Va.
JOSIAH MADISON ESTEP, Cleveland, Ohio.
GEORGE WASHINGTON GOETHALS, Culebra, Canal Zone, Panama.
LEMUEL HOLMES, Albany, N. Y.
CLIFFORD SHERRON MACCALLA, Spokane, Wash.
ALBERT REESOR RAYMER, Pittsburg, Pa.
WILLIAM HARPER ROBINSON, Manila, P. I.
JAMES REESE SCHICK, Roanoke, Va.
CHARLES SILLIMAN, Roanoke, Va.
CHARLES EDWARD WADDELL, Biltmore, N. C.

AS ASSOCIATE MEMBERS.

ALBERT AUGUST AEGERTER, St. Louis, Mo.
JOHN SCHUYLER BATES, Monmouth, Ill.
PHILIP BETHEL BOUDE, Central Islip, N. Y.
LLEWELLYN NATHANIEL EDWARDS, Montreal, Que., Canada.
WILLIAM ELLIS FORD, Little Rock, Ark.
THEODORE GREEN, Chicago, Ill.
WILLIAM SAMUEL HAMILL, Comstock, N. Y.
HARRY CHANDLER KITTREDGE, Lee Center, N. Y.
FRANK AUGUST LANG, New York City.
SALVADOR MARIA NAVARRETE, City of Mexico, Mex.
MORTON FRANKLIN SANBORN, Newton, Mass.
HARVEY OBED SCHERMERHORN, Waterford, N. Y.
HERMAN VICTOR SCHREIBER, Philadelphia, Pa.
MARTIN JACOB UNGRICH, New York City.
CHARLES THOMAS WARING, Culebra, Canal Zone, Panama.
CARLILE PATTERSON WINSLOW, Madison, Wis.

As Juniors.

Nathan Booker Buchanan, Huntsville, Ala.
Roland Parker Davis, Ithaca, N. Y.
Allen Stewart Davison, Pittsburg, Pa.
Paul Max Entenmann, New York City.
Pastor Gómez, Manila, P. I.
Harry Crocker Hutchins, New York City.
Myron Kendall Jordan, Denver, Colo.
Frank Alvah Kittredge, Seattle, Wash.
Harry Clifford McClure, Toledo, Ohio.
Frank Alwyn Marston, Roxbury, Mass.
Harrie Langdon Muchemore, Elizabeth, N. J.
Day Ira Okes, St. Louis, Mo.
Charles Ernest Ramser, Brooklyn, N. Y.
James Robinson Scott, Jr., Chicago, Ill.
Robert Brewster Stanton, Jr., Hamilton, Ohio.
David Bernard Steinman, New York City.
Charles Edward Stilson, Scottsbluff, Nebr.
Seth Martin Timberlake, Vail Gate, N. Y.
Daniel Rishel Weber, Monroe, Wash.
Harry Draper Winsor, White Plains, N. Y.

The Assistant Secretary announced the transfer of the following candidates by the Board of Direction on March 1st, 1910:

From Associate Member to Member.

Allan Winter Cuddeback, Paterson, N. J.
Harry Alfred Lane, Baltimore, Md.
Ora Miner Leland, Ithaca, N. Y.
Robert Athole MacGregor, New York City.
Frederick Charles Noble, Brooklyn, N. Y.
William Davis Uhler, Baltimore, Md.
Watson Vredenburgh, Jr., New York City.
Harry Roberts Wheeler, New York City.
William Pharo Wiltsee, Roanoke, Va.

From Junior to Associate Member.

William Howard Alderson, Chicago, Ill.
Edward Anderberg, Lockport, N. Y.
James Evans Barlow, Cincinnati, Ohio.
Elvin Jay Becker, Waterford, N. Y.
Roy Bullen, Salt Lake City, Utah.
William Peyton Day, San Francisco, Cal.
Jerome Henry Fertig, Montrose, Colo.

WALTER LEROY HUBER, San Francisco, Cal.
JUSTIN WYMAN LUDLOW, Chicago, Ill.
ARTHUR JAMES MCNEIL, Tracy, Cal.
CLAUDE IRVIN RHODES, San Francisco, Cal.
WALTER J RYAN, Cannon Ball, N. Dak.
CLARK LUZERNE WILCOX, Pittsburg, Pa.

FROM JUNIOR TO ASSOCIATE.

DAVID HEYDORN RAY, New York City.

The Assistant Secretary announced the death of WILLIAM MEIER, elected Associate Member June 1st, 1909; died February 14th, 1910.

Adjourned.

OF THE BOARD OF DIRECTION

(Abstract)

March 1st, 1910.—President Bensel in the chair; Chas. Warren Hunt, Secretary, and present, also, Messrs. Andrews, Belknap, Kimball, Loomis, Loweth, Macdonald, Pegram, Schneider, Thompson, and Wilkins.

The following resolution was unanimously adopted:

"Resolved that the Board of Direction heartily approves and endorses the action taken at a recent meeting of members of the Society in appointing a committee consisting of Charles Macdonald, Alfred Noble, William H. Burr, F. P. Stearns, and Samuel Whinery, with the object of urging suitable recognition of Civilian Engineers employed on River and Harbor Works, in the proposed legislation providing for an increase of the Engineer Corps of the Army."

Ballots for Membership were canvassed resulting in the election of 11 Members, 16 Associate Members, and 20 Juniors, the transfer of 9 Associate Members to the grade of Member, 1 Associate to the grade of Associate Member, 13 Juniors to the grade of Associate Member, and 1 Junior to the grade of Associate.

Applications were considered, and other routine business transacted.

Adjourned.

ANNOUNCEMENTS

The House of the Society is open from 9 A. M. to 10 P. M., every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

MEETINGS

April 6th, 1910.—8.30 P. M.—Two papers will be presented for discussion, as follows: "The New York Tunnel Extension of the Pennsylvania Railroad: The Terminal Station-West," by B. F. Cresson, Jr., M. Am. Soc. C. E.; and "The New York Tunnel Extension of the Pennsylvania Railroad: The Bergen Hill Tunnels," by F. Lavis, M. Am. Soc. C. E.

These papers were printed in *Proceedings* for February, 1910.

April 20th, 1910.—8.30 P. M.—At this meeting a paper by Herbert M. Wilson, M. Am. Soc. C. E., entitled, "Federal Investigations of Mine Accidents, Structural Materials, and Fuels, at the United States Testing Station, Pittsburg, Pa."

This paper was printed in *Proceedings* for February, 1910.

May 4th, 1910.—8.30 P. M.—Two papers will be presented at this meeting, as follows: "The Water Supply of the El Paso and Southwestern Railway, from Carrizozo to Santa Rosa, N. Mex.," by J. L. Campbell, M. Am. Soc. C. E.; and "The New York Tunnel Extension of the Pennsylvania Railroad: The Site of the Terminal Station," by George C. Clarke, M. Am. Soc. C. E.

These papers are printed in this number of *Proceedings.*

SUBSCRIPTION PRICE TO THE PUBLICATIONS OF THE SOCIETY

The following subscription rates have been fixed by the Board of Direction for the publications of the Society:

Proceedings, ten Numbers per annum, $8. Price for single numbers, $1.

Transactions, four Volumes per annum, $12. Price for single volumes, $4.

On the above prices there is a discount of 25% to members who desire extra copies of any of these publications, to Libraries, and to Book-dealers.

There is also an additional charge per annum, to cover foreign postage, of 75 cents for *Proceedings* and $1 for *Transactions,* or 8 cents and 25 cents, respectively, for single numbers.

A special subscription rate has been fixed by the Board for the *Proceedings* of the Society for the benefit of Students in Technical Schools. This rate is $4.50 per annum, and is available to any *bona fide* student of any technical school.

MEETINGS OF THE SAN FRANCISCO ASSOCIATION OF MEMBERS, AM. SOC. C. E.

The San Francisco Association of Members of the American Society of Civil Engineers holds regular bi-monthly meetings, with banquet and weekly informal luncheons. The former are held at 6 P. M., at the Fairmont Hotel, on the third Friday of February, April, June, August, October, and November, and also on the third Wednesday of December, the latter being the Annual Meeting of the Association.

Informal luncheons are held at 12.15 P. M. every Wednesday, and the place of meeting may be ascertained by communicating with the Secretary of the Association, E. T. Thurston, Jr., Assoc. M. Am. Soc. C. E., 623 Wells Fargo Building.

The by-laws of the Association provide for the extension of hospitality to any members of the Society who may be temporarily in San Francisco, and any such member will be gladly welcomed as a guest of the Association at any of the above meetings, if he will notify the Secretary that he is in San Francisco.

PAPERS AND DISCUSSIONS

Members and others who take part in the oral discussion of the papers presented are urged to revise their remarks promptly. Written communications from those who cannot attend the meetings should be sent in at the earliest possible date after the issue of a paper in *Proceedings.* The issue of volumes of *Transactions* is dependent on the closing of discussions, and the co-operation of the membership in this matter is essential to the regular issue of each quarterly volume.

All papers accepted by the Publication Committee are classified by the Committee with respect to their availability for discussion at meetings.

Papers, which, from their general nature, appear to be of a character suitable for oral discussion, will be published as heretofore in *Proceedings,* and set down for presentation to a future meeting of the Society, and, on these, oral discussion, as well as written communications, will be solicited.

All papers which do not come under this heading, that is to say, those which, from their mathematical or technical nature, in the opinion of the Committee, are not adapted to oral discussion, will not be scheduled for presentation to any meeting. Such papers will be published in *Proceedings* in the same manner as those which are to be presented at meetings, but written discussions, only, will be requested for subsequent publication in *Proceedings* and with the paper in the volumes of *Transactions.*

PRIVILEGES OF ENGINEERING SOCIETIES EXTENDED TO MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Members of the American Society of Civil Engineers will be welcomed by the following Engineering Societies, both to the use of their Reading Rooms and at all Meetings:

American Institute of Mining Engineers, 29 West Thirty-ninth Street, New York City.

Associação dos Engenheiros Civis Portuguezes, Lisbon, Portugal.

Australasian Institute of Mining Engineers, Melbourne, Victoria, Australia.

Boston Society of Civil Engineers, 715 Tremont Temple, Boston, Mass.

Brooklyn Engineers' Club, 117 Remsen Street, Brooklyn, N. Y.

Canadian Society of Civil Engineers, 413 Dorchester Street, West, Montreal, Que., Canada.

Civil Engineers' Society of St. Paul, St. Paul, Minn.

Cleveland Engineering Society, 718 Caxton Building, Cleveland, Ohio.

Cleveland Institute of Engineers, Middlesbrough, England.

Colorado Association of Members, Am. Soc. C. E., H. J. Burt, Secy., 235 Equitable Building, Denver, Colo.

Engineers' and Architects' Club of Louisville, Ky., 303 Norton Building, Fourth and Jefferson Streets, Louisville, Ky.

Engineers' Club of Baltimore, Baltimore, Md.

Engineers' Club of Minneapolis, 17 South Sixth Street, Minneapolis, Minn.

Engineers' Club of Philadelphia, 1317 Spruce Street, Philadelphia, Pa.

Engineers' Club of St. Louis, 3817 Olive Street, St. Louis, Mo.

Engineers' Club of Toronto, 96 King Street, West, Toronto, Ont., Canada.

Engineers' Society of Pennsylvania, 219 Market Street, Harrisburg, Pa.

Engineers' Society of Western Pennsylvania, 803 Fulton Building, Pittsburg, Pa.

Institute of Marine Engineers, 58 Romford Road, Stratford, London, E., England.

Institution of Engineers of the River Plate, Buenos Aires, Argentine Republic.

Institution of Naval Architects, 5 Adelphi Terrace, London, W. C., England.

Junior Institution of Engineers, 39 Victoria Street, Westminster, S. W., London, England.

Koninklijk Instituut van Ingenieurs, The Hague, The Netherlands.

Louisiana Engineering Society, 321 Hibernia Bank Building, New Orleans, La.

Memphis Engineering Society, Memphis, Tenn.

Midland Institute of Mining, Civil and Mechanical Engineers, Sheffield, England.

Montana Society of Engineers, Butte, Montana.

North of England Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne, England.

Oesterreichischer Ingenieur- und Architekten-Verein, Eschenbachgasse 9, Vienna, Austria.

Pacific Northwest Society of Engineers, 803 Central Building, Seattle, Wash.

Rochester Engineering Society, Rochester, N. Y.

Sachsischer Ingenieur- und Architekten-Verein, Dresden, Germany.

Sociedad Colombiana de Ingenieros, Bogota, Colombia.

Societe des Ingenieurs Civils de France, 19 Rue Blanche, Paris, France.

Society of Engineers, 17 Victoria Street, Westminster, S. W., London, England.

Svenska Teknologforeningen, Brunkebergstorg 18, Stockholm, Sweden.

Tekniske Forening, Vestre Boulevard 18–1, Copenhagen, Denmark.

Western Society of Engineers, 1737 Monadnock Block, Chicago, Ill.

SEARCHES IN THE LIBRARY

In January, 1902, the Secretary was authorized to make searches in the Library, upon request, and to charge therefor the actual cost to the Society for the extra work required. Since that time many searches have been made, and bibliographies and other information on special subjects furnished.

The resulting satisfaction, to the members, who have made use of the resources of the Society in this manner, has been expressed frequently, and leaves little doubt that, if it were generally known to the membership that such work would be undertaken, many would avail themselves of it.

The cost is trifling compared with the value of the time of an engineer who looks up such matters himself, and the work can be performed quite as well, and much more quickly, by persons familiar with the Library.

In asking that such work be undertaken, members should specify clearly the subject to be covered, and whether references to general

books only are desired, or whether a complete bibliography, involving search through periodical literature, is desired.

In reference to this work, the Appendix* to the Annual Report of the Board of Direction for the year ending December 31st, 1906, contains a summary of all searches made to that date.

LOCAL ASSOCIATIONS OF MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Colorado Association

(Abstract of Minutes of Meeting)

February 12th, 1910.—The regular meeting of the Colorado Association of Members, Am. Soc. C. E., was called to order at 8.30 P. M.; President H. S. Crocker in the chair; H. J. Burt, Secretary; and present also 20 members and 5 guests.

The minutes of the January meeting were read and approved.

The President appointed the following Committee on Legislation: George G. Anderson, Chairman, C. W. Comstock, James E. Maloney, Herbert W. Cowan, John E. Field, and M. S. Ketchum.

A paper on "The History and Development of the Preservation of Wood" was presented by Walter Buehler, M. Am. Soc. C. E., and the subject was discussed by Messrs. Toll, Sumner, Vincent, Ulrich, Betts, Riley, and others.

A motion was presented and adopted that the Colorado Association take the initiative in requesting the Board of Direction of the Society to appoint a Special Committee on Preservation of Wood.

Adjourned.

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* *Proceedings*, Vol. XXXIII, p. 20 (January, 1907).

ACCESSIONS TO THE LIBRARY

(From February 8th to March 7th, 1910)

DONATIONS*

THE THEORY AND PRACTICE OF MODERN FRAMED STRUCTURES.

Designed for the Use of Schools and for Engineers in Professional Practice. By J. B. Johnson, C. W. Bryan, M. Am. Soc. C. E., and F. E. Turneaure, Assoc. M. Am. Soc. C. E. Part I, Stresses in Simple Structures. Ninth Edition, Rewritten. Cloth, 9 x 6 in., illus., 12 + 328 pp. New York, John Wiley & Sons; London, Chapman & Hall, Limited, 1910. $3.00.

In preparing this edition the authors, it is stated, have decided to issue it in three parts and to adopt the octavo size, in the belief that this arrangement will make the work more convenient as a textbook and more useful as a reference book. Part I treats of simple structures, including beams and trusses; Part II will treat of structures requiring higher methods of analysis, such as swing bridges, arches, suspension and cantilever bridges, and will include a comprehensive treatment of secondary stresses; Part III will be devoted to the subject of design. The material in the present volume, which covers Chapters I to VII and Chapter XV of the old edition, has been rewritten and enlarged. The plan of carrying the graphical and algebraic methods along together has been followed with more attention to graphical processes. In this edition the plus sign is used for tension and the minus sign for compression. The contents are: Definitions and Historical Development; Elements of the Analysis of Framed Structures; Analysis of Roof Trusses; Analysis of Bridge Trusses for Uniform Loads; Analysis of Bridge Trusses for Concentrated Loads; Lateral Trusses, Trestles and Towers; Deflection of Structures and Stresses in Redundant Members; Index.

THE PROTECTION OF RAILROADS FROM OVERHEAD TRANSMISSION LINE CROSSINGS.

By Frank F. Fowle. Cloth, 7¾ x 5½ in., illus., 7 + 69 pp. New York, D. Van Nostrand Company, 1909. $1.50 net.

The protection of railroad property and the lives of railroad employees at overhead crossings of high-tension lines is stated to be the subject considered in this volume. The subject-matter was arranged for presentation before the Association of Railway Telegraph Superintendents at its Annual Meeting in 1908, but was not completed in time, and is, therefore, issued in this form. The author states that he has treated the subject by outlining a form of specification which will cover the general principles involved, the materials to be used, and the types of construction, without going into details pertaining to individual crossings. The Contents are: Protection of Life and Property on Railroads; What the Dangers Are; Effects of the Failure of a High-Tension Transmission Line at a Railroad Crossing; Examples of High-Tension Practice in Line Construction; Failures of High-Tension Lines; Screen Protection; Bridge and Catenary Types of Reinforced Crossing; Underground Crossings; Discussion of Proposed Type of Crossing; Typical Crossing.

ELECTRIC WAVES.

An Advanced Treatise on Alternating-Current Theory. By William Suddards Franklin. Cloth, 8¾ x 5¾ in., illus., 9 + 315 pp. New York, The Macmillan Company; London, Macmillan & Co., Ltd., 1909. $3.00 net.

The author states that as it is most important for the operating engineer to be familiar with the physics of machines, the object of this treatise is to develop the physical or conceptual aspects of wave motion, that is, "how much waves wave," and that, with the exception of the theory of coupled circuits and resonance, it is believed that the "how much" aspect of the subject is also developed to an extent commensurate with obtainable data and the results derived from them. While this treatise is stated to be complete both mathematically and physically, as far as it goes, the student is referred to other works for the more elaborate mathematical developments. Chapters I to VI treat of electric waves, with special reference to the phenomena of transmission and telephone lines; Chapter VII is

* Unless otherwise specified, books in this list have been donated by the publisher.

a brief discussion of electric-wave telegraphy; and Chapters VIII and IX treat of unharmonic electromotive forces and currents with respect to the behavior of commercial types of alternating-current machinery. The attention of the student is particularly called to the importance of Chapter VI, especially that part which treats of scalar and vector fields. The Contents are: Introduction; Part I, Electric Waves; Part II, Non-Harmonic Electromotive Forces and Currents; Appendix A, Inductance and Capacity of Transmission Lines; Appendix B, Electromagnetic and Electrostatic Systems of Units; Appendix C, Problems; Index.

FOWLER'S ELECTRICAL ENGINEER'S POCKET BOOK, 1910.

Edited by William H. Fowler. Tenth Annual Edition. Leather, $6\frac{1}{4}$ x 4 in., illus., 47 + 575 pp. Manchester, England, Scientific Publishing Company, 1910. 2 shillings 9 pence.

The subject-matter of this Pocket Book is stated to have been carefully revised and brought up to date and abreast with current practice. The Contents are: Miscellaneous Tables, etc.; Wire Tables; Magnetism and Magnetic Data; Conductors and Insulating Materials; Electric Lighting and Wiring; Comparison and Measurement of Resistances; Electrical Measuring Instruments; Electricity Meters; Primary and Secondary Batteries; Dynamos and Motors; Alternate Electric Currents; Alternators; Transformers; Alternate Current Motors; Switchboards, Circuit Breakers, and Lightning Arresters; Electrical Power Transmission and Distribution; Rotary Converters; Electric Traction; Rules and Regulations.

FOWLER'S MECHANICAL ENGINEER'S POCKET BOOK, 1910.

Edited by William H. Fowler. Twelfth Annual Edition. Leather, $6\frac{1}{4}$ x 4 in., illus., 71 + 655 pp. Manchester, England, Scientific Publishing Co., 1910. 2 shillings 9 pence.

In this edition a revision of all the data has been made, it is stated, and the sections dealing with mining machinery and appliances, and the metallurgy of iron and steel, have been rewritten and enlarged. The Contents are: Miscellaneous Tables and Formulæ; Steam Boilers and Fittings; Fuels and Combustion; Steam Engines; Steam Turbines; Locomotives; Steam Tables; Valves and Valve Gear; Gas Engines; Gases Used in Gas Engines; Oil Engines; Hydraulics; Pumps and Pumping Arrangements; Gearing and Lubrication; Hoisting and Lifting Machinery; Mining Machinery and Appliances; Metallurgy of Iron and Steel; Strength of Metals and Alloys; Beams and Pillars; Springs; Chemistry; Ventilation and Heating.

THE ENGINEERING INDEX ANNUAL FOR 1909.

Compiled from the Engineering Index Published Monthly in the *Engineering Magazine* During 1909. Cloth, $9\frac{1}{2}$ x $6\frac{1}{2}$ in., 471 pp. New York and London, The Engineering Magazine, 1910. $2.00.

The preface states that with this volume of The Engineering Index, a continuous index to the engineering and technical literature for the past twenty-six years is made available. In order to collate the entire literature of one subject and to assemble it in one place, the articles are arranged by divisions, viz.: Civil Engineering, Electrical Engineering, Industrial Economy, Marine and Naval Engineering, Mechanical Engineering, Mining and Metallurgy, Railway Engineering, and Street and Electric Railways. Under these headings they are grouped according to the special divisions of each field, the final arrangement under each section being alphabetical. In this edition it is stated that the classifications have been somewhat amplified and made more distinct, cross-references having been freely used. Serial articles are indexed on the appearance of the first installment only except in cases of articles in two or three installments, which are indexed entire. The list of periodicals indexed comprises about 250 publications, representing 17 nations and colonies, and 6 languages. A brief descriptive note is given with every entry, defining the scope and purport of the article. In general, the Index is intended for use as a guide to the information contained in files of engineering periodicals.

Gifts have also been received from the following:

Albany, N. Y.-City Engr. 1 pam.
Alexandra (Newport and Southend) Docks & Ry. Co. 1 pam.
Am. Electrochemical Soc. 1 pam.
Am. Inst. of Chemical Engrs. 1 bound vol.
Am. Locomotive Co. 2 pam.
Am. Ry. Assoc. 1 pam.
Am. Soc. Mech. Engrs. 1 bound vol.
Asbury Park, N. J.-Dept. of Water and Sewers. 3 pam.
Australasian Inst. of Min. Engrs. 1 vol.
Baker Street & Waterloo Ry. Co. 1 pam.

Baltimore & Ohio R. R. Co. 1 pam.
Binghamton, N. Y.-Board of Water Commrs. 1 pam.
Boston, Mass.-Special Comm. on the Collection and Disposition of Garbage and Offal. 1 bound vol.
Brooklyn, N. Y., Public Library. 1 pam.
Cambrian Rys. Co. 1 pam.
Canada-Dept. of Railways and Canals. 2 pam., 2 vol.
Canada-Geol. Survey Branch. 1 vol.
Central London Ry. Co. 1 pam.
Charing Cross, Euston & Hampstead Ry. Co. 1 pam.
Compagnie du Chemin de Fer du Congo. 1 pam.
Compagnie du Lomami. 1 pam.
Cornell Univ. Library. 1 pam.
Danvers, Mass.-Water Commrs. 1 pam.
Deutsch-Amerikanischer Techniker-Verband. 1 pam.
Engrs.' Club of Cincinnati. 1 bound vol.
Fall River, Mass.-Watuppa Water Board. 1 pam.
Ferrocarriles Nacionales de Mexico. 2 pam.
Furness Ry. 1 pam.
Geographical Soc. of Philadelphia. 1 pam.
Great Central Ry. Co. 1 pam.
Great Northern & City Ry. Co. 1 pam.
Great Northern, Piccadilly & Brompton Ry. Co. 2 pam.
Great Northern Ry. Co. (Ireland). 1 pam.
Great Western Ry. Co. 1 pam.
Green, Alice L. 1 pam.
Hull & Barnsley Ry. Co. 1 pam.
Huttern, Johann. 1 pam.
Illinois-State Highway Comm. 1 pam.
Inter. Assoc. for the Prevention of Smoke. 1 pam.
Iowa-Auditor of State. 1 bound vol.
Iron and Steel Inst. 1 bound vol.
Junior Institution of Engrs. 1 bound vol.
Lake Mohonk Conference of Friends of the Indian and other Dependent Peoples. 1 pam.
Lake Superior Min. Inst. 1 pam.
Leisen, Theodore A. 1 bound vol.
Liverpool Eng. Soc. 1 bound vol.
Liverpool Overhead Ry. Co. 1 pam.
London, Ont.-Board of Water Commrs. 1 pam.
London, Tilbury & Southend Ry. Co. 1 pam.
Mass. Inst. of Tech. 1 pam.
Mass. Inst. of Tech.-Class of '93. 1 pam.
Met. West Side Elev. Ry. Co. 1 pam.
Midland Ry. Co. 1 pam.
Modjeski, Ralph. 1 bound vol.
New York-State Museum. 3 bound vol.
New York State-Public Service Comm., First Dist. 3 bound vol., 1 vol.
New York State-Public Service Comm., Second Dist. 3 bound vol.
New York City-Visiting Committee of the State Charities Assoc. 2 pam.
New York Univ. 1 vol.
North London Ry. Co. 1 pam.
North Staffordshire Ry. Co. 1 pam.
Northampton, Mass.-Board of Water Commrs. 1 pam.
Ontario, Canada-Bureau of Mines. 1 bound vol.
Panama R. R. Co. 1 pam.
Pennsylvania-Dept. of Mines. 2 bound vol.
Pittsburg, Pa.-Dept. of Public Works. 8 vol.
Polytechnic Inst. of Brooklyn. 1 pam.
Raldiris, E. J. L. 1 pam.
Rhymney Ry. 1 pam.
Royal Philosophical Soc. of Glasgow. 1 pam.
Saskatchewan, Canada-Dept. of Public Works. 1 pam.
Schiffbautechnische Gesellschaft. 1 bound vol.
Soc. of Naval Architects and Marine Engrs. 1 pam.
Taff Vale Ry. Co. 1 pam.
Taunton, Mass.-Water Commrs. 1 pam.
U. S.-Block Signal and Train Control Board. 3 pam.
U. S.-Bureau of Statistics. 3 pam.
U. S.-Bureau of the Census. 1 pam.
U. S.-Chf. of Engrs. 72 pam.
U. S.-Coast and Geodetic Survey. 2 pam.
U. S.-Geol. Survey. 1 pam.
U. S.-Lake Survey Office. 1 map.
U. S.-Library of Congress. 1 bound vol.
U. S.-National Museum. 1 bound vol.
U. S.-Office of Exper. Stations. 1 pam.
U. S.-Supt. of Documents. 6 bound vol.
U. S.-Weather Bureau. 1 pam.
Wauters, Carlos. 1 vol.
Woolson, Ira H. 1 pam.
Yale Univ. 1 pam.

BY PURCHASE

Deutsche Bauzeitung: Sach-Register über die Jahrgänge, 1867-1900. 2 v. Carl Beelitz, Berlin, 1878; Deutsche Bauzeitung, G. m. b. H., Berlin, 1903.

Theorie der Elasticität und Festigkeit mit Bezug auf Ihre Anwendungen in der Technik. By Dr. F. Grashof. Second Edition, Revised and Enlarged. Rudolph Gaertner, Berlin, 1878.

Abwasserbeseitigung von Gewerben und Gewerbereichen Städten unter Hauptsächlicher Berücksichtigung Englands. By Albert Schiele. August Hirschwald, Berlin, 1909.

In Chancery of New Jersey, Between Mayor and Aldermen of Jersey City, Complainants, and Jersey City Water Company, Defendant. Vols. 11, 12, and Appendix. Press-Chronicle Company, Paterson, N. J., 1909.

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Illustrated Technical Dictionary in Six Languages: English, German French, Russian, Italian, Spanish. Edited by Alfred Schloman. Vol. 5-6. McGraw-Hill Book Company, New York, 1909.

Steam Power Plant Piping Systems: Their Design, Installation, and Maintenance. By William L. Morris. McGraw-Hill Book Company, New York, 1909.

Theoretical Elements of Electrical Engineering. By Charles Proteus Steinmetz. Third Edition. McGraw-Hill Book Company, New York, 1909.

The Cost of Mining: An Exhibit of the Results of Important Mines Throughout the World. By James Ralph Finlay. McGraw-Hill Book Company, New York, 1909.

The Modern Gas=Engine and the Gas=Producer. By A. M. Levin. John Wiley & Sons, New York; Chapman & Hall, Limited, London, 1910.

Linseed Oil and Other Seed Oils: An Industrial Manual. By William D. Ennis. D. Van Nostrand Company, New York, 1909.

Hydraulic Tables and Diagrams for Practical Engineers. By A. ff. Garrett. Longmans, Green & Co., London, New York, Bombay and Calcutta, 1909.

SUMMARY OF ACCESSIONS

(From February 8th to March 7th, 1910)

Donations (including 5 duplicates)	206
By purchase	22
Total	228

MEMBERSHIP

ADDITIONS

(February 8th to March 8th, 1910.)

MEMBERS		Date of Membership.
BRUNER, ABRAHAM. Asst. Engr., M. of W. Dept., Eastern Dist., Norfolk & West. Ry., Care, Norfolk & West. Ry., Roanoke, Va.		Mar. 1, 1910
CUDDEBACK, ALLAN WINTER. Engr. and Supt., Passaic Water Co., Paterson, N. J.	Assoc. M. M.	April 5, 1899 Mar. 1, 1910
EHLE, BOYD. Constr. Supt., J. G. White & Co., Scottsbluff, Nebr.	Assoc. M. M.	Jan. 3, 1894 Feb. 1, 1910
ESTEP, JOSIAH MADISON. Asst. Chf. Engr., Board of Public Service, 305 City Hall, Cleveland, Ohio		Mar. 1, 1910
FARLEY, PHILIP PATRICK. Pres., Jamaica Bay Impvt. Comm., 180 Montague St. (Res., 194 McDonough St.), Brooklyn, N. Y.	Jun. Assoc. M. M.	Oct. 31, 1893 Mar. 6, 1901 Feb. 1, 1910
GOVE, WILLIAM GRANVILLE. Supt. of Equipment, Brooklyn Rapid Transit System, 85 Clinton St., Brooklyn, N. Y.	Assoc. M. M.	Feb. 3, 1904 Feb. 1, 1910
JAUDON, HENRY SCUDDER. Cons. Engr., Savannah Water-Works System, P. O. Box 582, Savannah, Ga.	Assoc. M. M.	Feb. 4, 1903 Feb. 1, 1910
LANE, HARRY ALFRED. Asst. to Chf. Engr., M. of W., B. & O. R. R., B. & O. Bldg., Baltimore, Md.	Assoc. M. M.	Feb. 1, 1905 Mar. 1, 1910
LANT, FRANK PARSONS. Mgr., Lawyers Eng. and Surv. Co., 135 Broadway, New York City	Jun. M.	Oct. 3, 1888 Feb. 1, 1910
LEE, FRANCIS VALENTINE TOLDERVY. Asst. Gen. Mgr. and Chairman, Eng. Committee, Pacific Gas and Elec. Co. and San Francisco Gas and Elec. Co., San Francisco, Cal.; Address, 59th St., East of College Ave., Oakland, Cal.		Feb. 1, 1910
LELAND, ORA MINER. Asst. Prof., Coll. of Civ. Eng., Cornell Univ., and Chf. of Party Alaskan Boundary Comm., Cascadilla Bldg., Ithaca, N. Y.	Assoc. M. M.	Feb. 1, 1905 Mar. 1, 1910
MACGREGOR, ROBERT ATHOLE. Asst. Engr., Bureau of Highways, Borough of The Bronx (Res., 2428 Lorillard Pl.), New York City	Assoc. M. M.	Nov. 2, 1898 Mar. 1, 1910
MALMROS, NILS LORENTZ. Care, Ernest Flagg, 35 Wall St., New York City		Feb. 1, 1910
MASON, WILLIAM PITT. Prof. of Chemistry, Rensselaer Polytechnic Inst., and Water Specialist, Troy, N. Y.		Feb. 1, 1910

MEMBERS (*Continued*).

		Date of Membership.
MEEM, STEPHEN HALSEY. Civ. and Min. Engr. (Meem & Haskins), Bluefield, W. Va.		Feb. 1, 1910
MORRIS, MARSHALL, JR. Care, H. L. Stevens & Co., Houston, Tex.		Feb. 1, 1910
PAYNE, WILLIAM ARTHUR. Gen. Supt. of Constr. and Engr. with Charles T. Wills, Inc., 156 Fifth Ave., New York City		Feb. 1, 1910
SHEPHERD, FRANK CUMMINGS. Constr. Supt., J. G. White & Co., Inc., Jackson, Ga.	Assoc. M. M.	Oct. 5, 1904 Feb. 1, 1910
SHERMAN, EDWARD CLAYTON. Designing Engr., Isthmian Canal Comm., Culebra, Canal Zone, Panama	Assoc. M. M.	Jan. 3, 1906 Feb. 1, 1910
TAYLOR, GORHAM ANDREW. U. S. Engr.'s Office, Duluth, Minn.		Feb. 1, 1910
TYLER, WILLIAM DOWLIN. Chf. Engr., Clinchfield Coal Corp., Dante, Va.		Nov. 30, 1909
VREDENBURGH, WATSON, JR. Cons. and Inspecting Engr. (Hildreth & Co.), 135 Broadway, New York City	Assoc. M. M.	Mar. 6, 1901 Mar. 1, 1910
WHEELER, HARRY ROBERTS. Engr.-in-Chg., and Secy., Henry Steers, Inc., 17 Battery Pl., New York City	Jun. Assoc. M. M.	April 4, 1888 May 4, 1892 Mar. 1, 1910
WILTSEE, WILLIAM PHARO. Asst. Engr., Norfolk & Western Ry. Co., Roanoke, Va.	Assoc. M. M.	Oct. 7, 1903 Mar. 1, 1910

ASSOCIATE MEMBERS

ADAMS, CHARLES ROBERT. With Robert Follansbee, Engr., U. S. Geological Survey, Old Capitol Bldg., St. Paul, Minn.		Feb. 1, 1910
AEGERTER, ALBERT AUGUST. Care, A. B. Groves, 501 Stock Exchange Bldg., St. Louis, Mo.		Mar. 1, 1910
ANDERBERG, EDWARD. Asst. Engr., Barge Canal Office, Lockport, N. Y.	Jun. Assoc. M.	Mar. 5, 1907 Mar. 1, 1910
BARLOW, JAMES EVANS. Engr. with Bureau of Municipal Research, 911 Neave Bldg., Cincinnati, Ohio	Jun. Assoc. M.	Sept. 4, 1906 Mar. 1, 1910
BATES, JOHN SCHUYLER. City Engr., 231 South 4th St., Monmouth, Ill.		Mar. 1, 1910
BEALE, CARROLL. (Beale & Meigs), Washington Loan & Trust Bldg., Washington, D. C.		Oct. 5, 1909
CHANDLER, ELWYN FRANCIS. Prof. of Mathematics, State Univ. of North Dakota, University, N. Dak.		Feb. 1, 1910
CUTLER, ALVIN SAYLES. Asst. Prof. of Ry. Eng., Univ. of Minnesota, Minneapolis, Min.		Feb. 1, 1910

ASSOCIATE MEMBERS (*Continued*).		Date of Membership.
DOYING, WILLIAM ALBERT EDWARD. Inspecting Engr., Isthmian Canal Comm. (Res., 1627 Lamont St., N. W.), Washington, D. C		Feb. 1, 1910
DUNCAN, JAMES HARPER. Searsport, Me	Jun. Assoc. M.	Dec. 4, 1906 Feb. 1, 1910
FORD, HARRY CLIFFORD. Chf. Engr., Rodgers & Hagerty, Gen. Contrs., 417 West 150th St., New York City	Jun. Assoc. M.	Mar. 6, 1906 Feb. 1, 1910
FOUILHOUX, JACQUES ANDRÉ. Cons. Engr. (Lazarus, Whithouse & Fouilhoux), Portland, Ore		Oct. 5, 1909
FREW, ARCHIBALD JOHN RUSSELL. Engr. in Chg. of Constr. of Section of The Chilagoe-Etheredge Ry., Malloy, North Queensland, Australia		Oct. 5, 1909
HOOD, HUGH KENDALL. Res. Engr. for B. H. Hardaway, Blacksburg, S. C		Feb. 1, 1910
HUNTINGTON, LINN MURDOCH. Ingeniero Civil, Dirreccion General de Obras Publicas, Santo Domingo, Santo Domingo	Jun. Assoc. M.	May 2, 1905 Aug. 31, 1909
INSLEY, WILLIAM HENRY. Cons. Engr.; Gen. Mgr., The Insley Mfg. Co., Indianapolis, Ind		Aug. 31, 1909
IRISH, LELAND WESLEY. Asst. Prof. of Civ. Eng., Coll. of Eng., Northwestern Univ.; Address, 808 Hamilton St., Evanston, Ill.	Jun. Assoc. M.	Feb. 4, 1908 Feb. 1, 1910
LANAGAN, FRANK RAY. Deputy City Engr. (Res., 273 Hamilton St.), Albany, N. Y.	Jun. Assoc. M.	Sept. 5, 1905 Feb. 1, 1910
MAHON, ROSS LEHUNT. U. S. Engr. Office, Sault Ste. Marie, Mich		Feb. 1, 1910
MARSHALL, URBAN SERENUS. Engr. of the Colusa County Highway Comm.; City Engr., Box 96, Roseville, Cal		Feb. 1, 1910
MEARS, FREDERICK. Chf. Engr., Panama R. R. Co., Cristobal, Canal Zone, Panama		Feb. 1, 1910
MORITZ, ERNEST ANTHONY. Sunnyside, Wash.	Jun. Assoc. M.	Oct. 6, 1908 Jan. 4, 1910
NEWELL, ROBERT J. Asst. Engr., Constr. of Salmon River Dam, Twin Falls, Idaho		Feb. 1, 1910
O'NEIL, JOSEPH. City Engr., 608 Olive St., Leavenworth, Kans		Feb. 1, 1910
SANBORN, MORTON FRANKLIN. Asst. Engr., Charles River Basin Comm. of Massachusetts, 19 Baldwin St., Newton, Mass		Mar. 1, 1910
SAUNDERS, WALTER BOWEN. Care, H. M. Byllesby & Co., 218 La Salle St., Chicago, Ill		Jan. 4, 1910

ASSOCIATE MEMBERS (*Continued*).

		Date of Membership.
SCHERMERHORN, HARVEY OBED. Asst. Res. Engr., Residency No. 1, Erie Canal, Waterford, N. Y.		Mar. 1, 1910
SLATTERY, LAWRENCE PATRICK. Asst. Engr. with J. E. Sirrine, Greenville, S. C.		Feb. 1, 1910
UNGRICH, MARTIN JACOB. Asst. Engr., Board of Water Supply of New York City, 299 Broadway, New York City		Mar. 1, 1910
WARING, CHARLES THOMAS. Asst. Engr., Cape Cod Canal, Buzzards Bay, Mass.		Mar. 1, 1910
WILCOX, CLARK LUZERNE. Treas., The Pitt Constr. Co., Inc., 821 Fulton Bldg., Pittsburg, Pa.	Jun. Assoc. M.	Dec. 3, 1901 Mar. 1, 1910
YEO, WILLIAM HERBERT WATT. Junior Engr., U. S. Reclamation Service, Las Cruces, N. Mex.		Feb. 1, 1910

ASSOCIATES

CURREY, JESSE ALBERT. Northwest Mgr., Trussed Concrete Steel Co., 1007 Board of Trade, Portland, Ore.		Feb. 1, 1910
RAY, DAVID HEYDORN. Instr. in Physics and Mechanics, Coll. of the City of New York (Res., 2273 Creston Ave., Bronx), New York City	Jun. Assoc.	Oct. 7, 1902 Mar. 1, 1910
RYAN, LAURENCE PATRICK. Contr. (T. L. Ryan & Co.), 4047 Kenmore Ave., Chicago, Ill.		Aug. 31, 1909
SOMMER, ALBERT. Cons. Chemist of The Texas Co., 17 Battery Pl., New York City		Feb. 1, 1910

JUNIORS

ABRONS, LOUIS WILLIAM. Asst. Engr., Bureau of Public Works, Manila, Philippine Islands	Aug. 31, 1909
ACKEMANN, HENRY CONRAD. Bridge Insp., Illinois State Highway Comm., 110 Hill St., Elgin, Ill.	Feb. 1, 1910
ATWOOD, CHESTER ELY. Draftsman for The Conrad Land & Water Co., Valier, Mont.	Feb. 1, 1910
BIGELOW, WILLIAM WALTER. 399 Lexington St., Waltham, Mass.	Feb. 1, 1910
BROWN, CLAUDE OSGOOD. Asst. Engr., Bureau of Public Works, Manila, Philippine Islands	Oct. 5, 1909
CHACE, AMASA MANTON. 10 Bay View Ave., Newport, R. I.	Oct. 5, 1909
DENNIE, FRANK EDWARD. Univ. of Missouri School of Mines and Metallurgy, Rolla, Mo.	Oct. 5, 1909
DUMOULIN, WALTER LOUIS. Supt., The Morenci Water Co., Morenci, Ariz.	Feb. 1, 1910
HAZEN, RALPH WILLIAM. Asst. Engr., Bureau of Public Works, Manila, Philippine Islands	Nov. 30, 1909

JUNIORS (*Continued*).

	Date of Membership.
HUTCHINS, HARRY CROCKER. Draftsman, Public Service Comm., First Dist., 154 Nassau St. (Res., 15 West 107th St.), New York City	Mar. 1, 1910
NORWOOD, EDGAR ALVA. 19 Mason St., Medford Hillside, Mass.	Nov. 30, 1909
PARET, JOHN WALDO. With Wichita Falls and Northwestern Ry., Carter, Okla.	Feb. 1, 1910
PATERSON, CHARLES JUDSON. Box 982, Oklahoma, Okla.	Feb. 1, 1910
RICHARDS, ARTHUR. Gatun, Canal Zone, Panama	Jan. 4, 1910
SIELING, LOUIS JOHN. 539 Linwood St., Brooklyn, N. Y.	Feb. 1, 1910
TRASK, WARREN DUDLEY. Draftsman with The Conrad Land & Water Co., Valier, Mont.	Feb. 1, 1910
WILLCOX, JAMES DEWITT. Draftsman with Field, Fellows & Hinderlider, 435 New Century Bldg., Denver, Colo.	Feb. 1, 1910
WILMOT, SYDNEY. Care, Office of Public Roads, Washington, D. C.	Nov. 8, 1909
WINSOR, HARRY DRAPER. Rodman, Board of Water Supply of New York City, 137 South Broadway, White Plains, N. Y.	Mar. 1, 1910
WOODRUFF, CHARLES WILLIAM. Cons. Engr., Room 420, Henry Bldg., Portland, Ore.	Jan. 4, 1910

CHANGES OF ADDRESS

MEMBERS

ADAMS, EDWIN GRIGGS, JR. Care, James E. Guyer, Waverly, N. Y.

BAKENHUS, REUBEN EDWIN. Civ. Engr., U. S. N., U. S. Naval Stations, Cavite and Olongapo, Philippine Islands.

BLAKE, CARROLL. Care, The Fred A. Jones Co., Houston, Tex.

BRIGGS, JOSIAH ACKERMAN. Cons. Engr., 150 Nassau St., New York City.

BROWNELL, ERNEST HENRY. Civ. Engr., U. S. N., Care, Bureau of Yards and Docks, Navy Dept., Washington, D. C.

CHAMBERS, FRANK TAYLOR. U. S. Navy Yard, Mare Island, Cal.

CHITTENDEN, HIRAM MARTIN. Brig.-Gen. U. S. A. (*Retired*), 124 Fifteenth Ave. N., Seattle, Wash.

CORTHELL, ELMER LAWRENCE. 149 Broadway, New York City.

CRUMP, RALPH LEE. Merchantville, N. J.

FENN, ROBERT WILLSON. Mgr., Mfg. Dept., Union Oil Co. of California, Mills Bldg., San Francisco, Cal.

FORD, PORTER DWIGHT. 443 Church St., Richmond Hill, N. Y.

HEDRICK, IRA GRANT. Cons. Engr., 1118 McGee St., Kansas City, Mo.

HOWELLS, JULIUS MERRIAM. Hydr. Engr., "Trianon" Ave. Juste Olivier, Lausanne, Switzerland.

MEMBERS (*Continued*).

KENNEDY, JAMES HENRY. Asst. Chf. Engr., Vancouver, Victoria & East. Ry. & Nav. Co., G. N. Ry. Depot, Vancouver, B. C., Canada.

KINGMAN, LEWIS. Engr., M. of W., National Railways of Mexico, Buenavista (Res., 1-A Liverpool No. 3, Mexico City), Mexico.

LALL, CHIRANJI. Head Master, Govt. School of Engrs., Punjab, Nila Gumbad, Haveli L. Mool Chand Merchant, Lahore, Punjab, India.

MCKINSTRY, CHARLES HEDGES. Maj., Corps of Engrs., U. S. A. Manila, Philippine Islands.

REED, PAUL LYON. Civ. Engr., U. S. N., Bureau of Yards and Docks, Washington, D. C.

SCOFIELD, GLENN MASON. Cons. Engr., 1324 Arcade Bldg., Philadelphia, Pa.

SMITH, AUGUSTUS. The Bergen Point Iron Works, Foot of West 5th St., Bayonne, N. J.

STEECE, EMMET ABNER. Supt. of Constr., U. S. Public Bldgs., Fayetteville, Ark.

TEMPLE, JOHN CHARLES. Care, S. Morgan Smith, 644 American Trust Bldg., Chicago, Ill.

THOMSON, ERNEST BURSLEM. U. S. Asst. Engr., U. S. Engr. Office, Portland, Ore.

WAUTERS, CARLOS. Avenida de Mayo, 878, Buenos Aires, Argentine Republic.

WINSLOW, BENJAMIN EMANUEL. Structural Engr., 1527 N. California Ave., Chicago, Ill.

WOODMAN, ANDREW WHITNEY. 184 La Salle St., Chicago, Ill.

ZESIGER, ALBERT WILLIAM. Care, William H. Evers Eng. Co., The Arcade, Cleveland, Ohio.

ASSOCIATE MEMBERS

AGRAMONTE, ALBERT ARTHUR. Care, Francisco Etchevarne, Venezuela, 8F1, Argentine Republic.

ASH, LOUIS RUSSELL. 1118 McGee St., Kansas City, Mo.

BAKER, HENRY ERSKINE. Engr., Chinese Govt. Paper Mills, Han Kow, China.

BLACK, EDWARD FRYLING. Instr. in Eng., Anglo-Chinese Coll., Foochow, China.

BROWNELL, LEONARD DEMPSTER. 112 So. Chester St., Syracuse, N. Y.

BRUSH, CARL FLETCHER. Chf. Engr., Charles City West. Ry., Charles City, Iowa.

BURNS, LOUIS ANDREW. Asst. Engr., New York State Barge Canal, Phœnix, N. Y.

BUTTERFIELD, HERBERT MITCHELL. Care, Riley, Hargreaves & Co., 5 Battery Rd., Singapore, Straits Settlements.

CAMERON, HARRY FRANK. Acting Dist. Engr., XI Eng. Dist., Cebu, Philippine Islands.

CONNELL, HENRY LEO. Asst. Engr., Board of Water Supply of New York City, Pleasantville, N. Y.

ASSOCIATE MEMBERS (*Continued*).

CRAIN, ARTHUR MANCHESTER. Secy. and Treas., Gate City Constr. Co. of Omaha, Nebr., 339 Century Bldg., Denver, Colo.

DARLING, JOHN WHITSON. Asst. Engr., N. Y. C. & H. R. R. R., 145 Washington St., Buffalo, N. Y.

FOUGNER, HERMANN. Civ. Engr. and Agent, Trussed Concrete Steel Co., 25 Madison Sq., North, New York City.

FRASQUIERI Y REGUEIFERO, TRANQUILINO. Luz 97, Havana, Cuba.

GALBREATH, WILLIAM OTTO. Div. Engr., National Railways of Mexico, Calle Colegio Civil No. 105, Monterey, N. L., Mexico.

GELLATLY, JOHN THOMPSON BISSET. Cons. Engr., Cala, Transkeian Territories, Cape Colony, South Africa.

HARPS, HARRY MACY. Res. Engr., Celilo Bridge, Celilo, Ore.

HOLT, LESTER MORTON. 629 Massachusetts Ave., N. E., Washington, D. C.

IMMEDIATO, GERARDO. 53 North Willow St., Montclair, N. J.

JOHANNESSON, SIGVALD, 317 Park Ave., Newark, N. J.

JOHNSON, EDWIN SAMUEL. Superv. Bldg. Engr., Archt.'s Office, Can. Pac. Ry., Windsor Station, Montreal, Que., Canada.

KAUFMAN, VERNET ALBERT. 410 Kittredge Bldg., Denver, Colo.

KYLE, GEORGE ALLEN. 609 Henry Bldg., Portland, Ore.

MANTER, RALPH BARTON. Locating Engr., Ferrocarril del Cauca, Cali, Colombia.

MCDONOUGH, MICHAEL JOSEPH. Capt., Corps of Engrs., U. S. A., Fort Santiago, Manila, Philippine Islands.

MINNISS, GEORGE STEWART. (Ricker & Minniss), 702 Ellicott Sq., Buffalo, N. Y.

MONTGOMERY, ERNEST. Div. Engr., The Orchard Constr. Co. of Chicago, Box 226 Littleton, Colo.

MORRILL, WILBUR NATHANIEL. Managing Engr. for The Weber Co., 18th and Stratton Sts. Louisville, Ky.

MOZART, WILLIAM JACOB. Cons. and Constr. Engr., P. O. Box G, Cannon Falls, Minn.

MURPHY, ROBERT LINCOLN. Treas., Murphy Constr. Co., East St. Louis, Mo.

PAIGE, JASON. 220 Audubon Ave., New York City.

POE, ALLAN TINKER, JR. 45 West Peachtree Pl., Atlanta, Ga.

POTTER, JAMES ROWLAND. Civ. Engr. and Contr., 400 Coleman Bldg., Philadelphia, Pa.

ROBINSON, FRANK MINER. Roadmaster, West. Pac. Ry.; Box 258, Oroville, Cal.

TAFT, JESSE RUSSELL. Care, Colonial Eng. and Constr. Co., 1 Madison Ave., New York City.

TALBOT, EARLE. 62 Connecticut Apartments, Washington, D. C.

TARR, CHARLES WINTHROP. 190 Columbia Heights, Brooklyn, N. Y.

TIFFANY, NELSON OTIS, JR. Engr. and Contr. (Tiffany & Gail), 13 Erie Co. Bank Bldg., Buffalo, N. Y.

WILLIAMS, HOWARD SHAY. Washington Apartments, Cleveland, Ohio.

ASSOCIATE MEMBERS (*Continued*).

WISE, JAMES HUGH. Cons. Civ. and Hydr. Engr., with G. A. Baum, 1404 Chronicle Bldg., San Francisco, Cal.

WITHAM, MYRON ELLIS. Cons. Engr. (Bull & Witham), 411 Commonwealth Bldg., Denver, Colo.

YEN, TE CHING. Asst. Chf. Engr., Szechuen Chuenhan Ry. Co., Ichang, China.

JUNIORS

ANDERSON, LOWREY WALLACE. Chf. Engr., Pecos & Toyah Val. Ry., Pecos, Tex.

BIGGS, CARROLL ADDISON. 219 West Franklin Ave., Jackson, Mich.

BILYEU, CHARLES SMITH. Operating Dept., Am. Bridge Co., Ambridge, Pa.

CHADWICK, CHESTER ROBERT. Estimator Designer, Milliken Bros. Inc., Milliken, N. Y.

DRIGGS, EDWIN LEROY. 4 Robles, Ermita, Manila, Philippine Islands.

ERDMANN, EARL EDWIN. Bridge Insp., C. M. & P. S. Ry., 1618 East Lake Ave., Seattle, Wash.

HOLMES, ROBERT LESLIE. Asst. Engr., Tex. & Pac. Ry. Co., Dallas, Tex.

HOWARD, CLEMENT JOHN. Eng. Dept., The Texas Co., Houston, Tex.

JOHNSON, LUTHER ELMAN. Asst. Engr., U. S. Reclamation Service, Burley, Idaho.

KILKENNY, TOBIAS DILLON. 930 Pine St., San Francisco, Cal.

LAMB, WILLIAM ALFRED. Asst. Engr., Care, Water Resources, U. S. Geological Survey, Washington, D. C.

MILLARD, CURTISS. Engr., M. of W., Chic. Gt. West. R. R. Co., Des Moines, Iowa.

MILLER, HUGH. Prof. of Civ. Eng., Clarkson School of Technology, Potsdam, N. Y.

NEUHARDT, EDWIN. Insp., Constr., City Eng. Dept., City Hall, Memphis, Tenn.

PORTER, HARRY FRANKLIN. 70 Kenyon Bldg., Louisville, Ky.

STEWART, CHARLES SUMNER. Care, Chic. & Wisconsin Val. R. R., Portage, Wis.

SUAREZ Y CORDOVES, PATRICIO ANDRES. G. Esquina A 11, Vedado, Havana, Cuba.

WILEY, HUGH LEMUEL. 1040 East Main St., Portland, Ore.

WRIGHT, THOMAS JUDSON, JR. Bandy, Tazewell Co., Va.

DEATHS

BARNARD, JOHN FISKE. Elected Member, September 1st, 1880; died February 6th, 1910.

HORAN, JOHN JOSEPH. Elected Associate Member, October 7th, 1908; died November 9th, 1909.

LIVINGSTON, JULIUS I. Elected Associate, July 3d, 1889; died March 1st, 1910.

MEIER, WILLIAM. Elected Associate Member, June 1st, 1909; died February 14th, 1910.

THOMSON, GEORGE HUNTINGTON. Elected Member, February 2d, 1887; died February 7th, 1910.

WEBSTER, FRANK WALLACE. Elected Associate Member, May 6th, 1908; died February 15th, 1910.

Total Membership of the Society, March 8th, 1910,
5 356

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST

(February 8th to March 7th, 1910)

NOTE.—*This list is published for the purpose of placing before the members of the Society, the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles, references are given by the number prefixed to each journal in this list:

(1) *Journal*, Assoc. Eng. Soc., 31 Milk St., Boston, Mass., 30c.
(2) *Proceedings*, Engrs. Club of Phila., 1317 Spruce St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Engrs., Monadnock Blk., Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Canada.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(8) *Stevens Institute Indicator*, Stevens Inst., Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 25c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 25c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c.
(14) *Engineering Record*, New York City, 12c.
(15) *Railway Age Gazette*, New York City, 15c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Electric Railway Journal*, New York City, 10c.
(18) *Railway and Engineering Review*, Chicago, Ill., 10c.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England, 25c.
(22) *Iron and Coal Trades Review*, London, England, 25c.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gas Light Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World*, New York City, 10c.
(28) *Journal*, New England Water-Works Assoc., Boston, Mass., $1.
(29) *Journal*, Royal Society of Arts, London, England, 15c.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales* de l'Assoc. des Ing. Sortis des Ecoles Spéciales de Gand, Brussels, Belgium.
(32) *Mémoires et Compte Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economiques des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(37) *Revue de Mécanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Proceedings*, Am. Inst. Elec. Engrs., New York City, 50c.
(43) *Annales des Pontes et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governors Island, New York Harbor, 50c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 8c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift*, Verein Deutscher Ingenieure, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Düsseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift*, Oesterreichischer Ingenieur und Architekten Verein, Vienna, Austria.
(54) *Transactions*, Am. Soc. C. E., New York City, $4.
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(57) *Colliery Guardian*, London, England.
(58) *Proceedings*, Engrs.' Soc. W. Pa., 803 Fulton Bldg., Pittsburg, Pa., 50c.
(59) *Transactions*, Mining Inst. of Scotland, London and Newcastle-upon-Tyne, England.
(60) *Municipal Engineering*, Indianapolis, Ind., 25c.
(61) *Proceedings*, Western Railway Club, 225 Dearborn St., Chicago, Ill., 25c.
(62) *Industrial World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E., London, England.
(64) *Power*, New York City, 20c.
(65) *Official Proceedings*, New York Railroad Club, Brooklyn, N. Y., 15c.
(66) *Journal of Gas Lighting*, London, England, 15c.
(67) *Cement and Engineering News*, Chicago, Ill., 25c.
(68) *Mining Journal*, London, England.
(70) *Engineering Review*, New York City, 10c.
(71) *Journal*, Iron and Steel Inst., London, England.
(71*a*) *Carnegie Scholarship Memoirs*, Iron and Steel Inst., London, England.
(73) *Electrician*, London, England, 18c.
(74) *Transactions*, Inst. of Min. and Metal., London, England.
(75) *Proceedings*, Inst. of Mech. Engrs., London, England.
(76) *Brick*, Chicago, Ill., 10c.
(77) *Journal*, Inst. Elec. Engrs., London, England.
(78) *Beton und Eisen*, Vienna, Austria.
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(86) *Engineering-Contracting*, Chicago, Ill., 10c.
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(88) *Bulletin* of the International Ry. Congress Assoc., Brussels, Belgium.
(89) *Proceedings*, Am. Soc. for Testing Materials, Philadelphia, Pa.
(90) *Transactions*, Inst. of Naval Archts., London, England.
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(92) *Bulletin*, Soc. d'Encouragement pour l'Industrie Nationale, Paris, France.
(93) *Revue de Métallurgie*, Paris, France, 4 fr. 50.
(94) *The Boiler Maker*, New York City, 10c.
(95) *International Marine Engineering*, New York City, 20c.
(96) *Canadian Engineer*, Toronto, Canada, 15c.
(97) *Turbine*, Berlin, Germany, 1 Mark.
(98) *Journal*, Engrs. Soc. Pa., 219 Market St., Harrisburg, Pa., 30c.
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LIST OF ARTICLES

Bridges.

Boylston Street Bridge, Boston, from 1888 to the Present Time; the Destruction and Reconstruction of a Bridge Subjected to Locomotive Fumes and Increasing Street Car Loads.* Frederic H. Fay, Charles M. Spofford and John C. Moses. (Paper read before the Bost. Soc. of Civ. Engrs.) (1) Dec.
Report on the Question of the Strengthening the Bridges with a View to Increasing the Weight of Locomotives and the Speed of Trains. (Subject for Discussion at the 8th Sess. of the Ry. Cong.)* Labes. (88) Jan.
Bascule Bridge at Copenhagen.* (12) Feb. 4.
A Novel Method of Striking Steel Centers for 150-ft. Concrete Arch Spans.* (86) Feb. 9.
Moving a Railroad Bridge Transversely.* (14) Feb. 12.
The Governor Reynolds Reinforced-Concrete Bridge, Province of Albay, Philippine Islands.* Oliver D. Filley. (13) Feb. 17.
Types of Highway Bridges.* F. Barber, A. M. Can. Soc. C. E. (96) Serial beginning Feb. 18.
Erection Appliances for the Belly River Viaduct at Lethbridge, Alberta.* (13) Feb. 24.
The Albemarle Sound Trestle of the Norfolk & Southern Railway.* F. L. Nicholson. (15) Feb. 25; (18) Feb. 26.
Tests of Models of the Medina Aqueduct Arch.* (From *Barge Canal Bulletin.*) (14) Mar. 5.
Reconstruction of Boylston Street Bridge at Boston.* (14) Mar. 5.

*Illustrated.

Bridges—(Continued).

Les Moyens de Communication entre les Deux Rives de l'Escaut, à Anvers.* R. v. d. Mensbrugghe. (31) 1909, Pt. 3.
La Reconstruction du Pont Notre-Dame, à Paris.* (33) Jan. 29.
Les Ponts Métalliques au Yun-Nan (Chine), Pont sur le Faux Nam-Ti.* Georges Bodin. (33) Feb. 12.

Electrical.

Electrical Transmission by Polycyclic Currents.* Charles F. Smith, M. Inst. E. E. (47) Serial beginning Feb. 4.
Rates for Electric Current Furnished by the Municipal Plant of Pasadena, Cal. (13) Feb. 10.
Castelnuovo-Valdarno Transmission Plant.* (27) Feb. 10.
Some Engineering Features of the Hakone, Japan, Hydroelectric Plant. S. Motomura. (27) Feb. 10.
Economics of Synchronous Condensers.* B. F. Jakobsen. (27) Feb. 10.
Rates for Hydroelectric Service. Alton D. Adams. (27) Feb. 10.
The Automatic Electric Company's Telephone System.* (11) Serial beginning Feb. 11.
A New Arc Lamp.* P. A. Mossay. (73) Feb. 11.
The Present Position of the Theory of Commutation.* J. Sumec. (Abstract from *Elektrotechnik Zeit.*) (73) Serial beginning Feb. 11.
Modern Arc Lamps and their Application. A. Angold. (Abstract of paper read before the Assoc. of Engrs.-in-Charge.) (73) Feb. 11.
Power Station Improvements at Terre Haute.* (17) Feb. 12.
Engelberg-Lucerne Transmission System.* Francis M. Weldon. (27) Feb. 17.
Note on the Use of Kapp's Apparatus for Measuring Permeability of Iron under High Magnetising Forces.* R. Beattie and H. Gerrard. (73) Feb. 18.
Wireless Telegraph Mast at Stoke-By-Nayland Vicarage.* (73) Feb. 18.
Water Power Plant at Stangfjord, Norway.* (73) Feb. 18.
New Substations in Chicago; a Brief Account of Isolated and Combination Stations of the Commonwealth Edison Company.* (27) Feb. 24.
The Induction Generator.* Thomas Spooner and A. J. Barnes. (27) Feb. 24.
The Flicker Photometer.* J. S. Dow. (27) Feb. 24.
Heterochromatic Photometry.* David Edgar Rice. (27) Feb. 24.
The Radiation from Directive Aerials in Wireless Telegraphy.* L. H. Walter. (From *Jahrbuch der drahtlosen Telegraphie.*) (73) Feb. 25.
Tantalum Filament Characteristics.* L. Crouch. (73) Feb. 25.
Power Factor Correction.* (12) Serial beginning Feb. 25.
Les Applications de l'Electricité à l'Exposition de Marseille et le 1er Congrès International d'Electricité.* Lasalle and Gevaert. (30) Feb.
Die Elektrische Lokalbahn Trient-Malè und die Neuen Elektrizitätswerksanlagen der Stadtgemeinde Trient.* Paul Dittes. (53) Serial beginning Jan. 28.

Marine.

Turbine Propulsion, Recent Developments. R. M. Neilson. (95) Feb.
The New Castle Liner *Balmoral Castle.** (95) Feb.
Electrical Equipment of Smith's Docks, North Shields.* (73) Feb. 4.
Two, Three or Four Propellers? (12) Feb. 4.
New Steamers for the Nippon Yusen Kaisha.* (11) Serial beginning Feb. 4.
Steel Barges for Rock. (From *Marine Review.*) (14) Feb. 12.
A Legal Decision Regarding the Boston Dry Dock. (14) Feb. 12.
The Lifeboat and its Work. John Cameron Lamb. (29) Feb. 18.
A Self-Dumping Barge.* (11) Feb. 18.
American Marine Turbines and Gearing.* (12) Feb. 18.
Spur Wheel Reduction Gear for Steam Turbines.* (47) Feb. 25.
Corrugated Sides on S. S. *Monitoria* and their Effect. A. H. Haver. (Paper read before the North-East Coast Inst. of Engrs. and Shipbuilders.) (12) Feb. 25.
Boiler Attachments and Funnel Draft. H. K. Spencer. (95) Mar.
The *Prinses Juliana.** (95) Mar.
The Effect of Superheat on the Economy of a Marine Engine as Determined by Tests on the Steam Yacht *Idalia.** John Halligan, Jr. (From *Journal,* Amer. Soc. of Naval Engrs.) (95) Mar.
Barges of Concrete to be Built at Panama. (From *Canal Record.*) (13) Mar. 3; (86) Mar. 2; (14) Mar. 5.
Le Cuirassé Brésilien *Minas Geraes.** E. Lignorelles. (33) Feb. 19.
Die Eisenbahnfährschiffe *Deutschland* und *Preussen.** W. Kaemmerer. (48) Jan. 1.

Mechanical.

A Bituminous Power Gas Producer.* E. F. Bulmahn. (58) Jan.
Air-Separators in Cement Plants. O. Pfeiffer. (67) Feb.
Plaster, Overburnt Gypsum and Hydraulic Gypsum.* M. Glasenapp. (67) Serial beginning Feb.

*Illustrated.

Mechanical—(Continued).

Boiler Explosions and Riveted Joints. James Crombie. (Abstract of paper read before the C. A. S. E.) (94) Feb.
Testing Suction Gas-Producers with a Körting Ejector.* C. M. Garland and A. P. Kratz. (Abstract.) (66) Feb. 1.
The Design of Surface Condensers.* R. M. Neilson. (Paper read before the Inst. of Engrs. and Shipbuilders in Scotland.) (47) Serial beginning Feb. 4.
The Parker Down-Flow Water-Tube Boiler.* (11) Feb. 4.
Test of a Compound Semi-Stationary Superheated Steam Engine.* (12) Feb. 4.
The Causes and Ranges of Variation in Calorimetric Tests. Thomas Holgate, M. Inst. C. E. (66) Serial beginning Feb. 8.
The Flow of Gas through Pipes. D. Chandler. (66) Feb. 8.
The Humphrey Gas-Pump.* (11) Feb. 11.
Evence-Coppee Waste Heat Coke Oven Plant at Pinxton.* (57) Feb. 11.
The Power Station of the Allis-Chalmers Works.* (14) Feb. 12.
An Internal-Combustion Pump, Applications of a New Principle.* Herbert A. Humphrey. (19) Serial beginning Feb. 12.
A Description of a Retort House.* Charles D. Lamson. (Paper read before the Amer. Gas Inst.) (24) Serial beginning Feb. 14.
Gas-Works Calorimetry. P. C. Balcon. (Paper read before the Midland Junior Gas Assoc.) (66) Feb. 15.
Directions for Working Steam Road Rollers and Steam Traction Engines. (86) Feb. 16.
Motors for Aerial Navigation.* J. S. Critchley. (Paper read before the Inc. Inst. of Automobile Engrs.) (47) Serial beginning Feb. 18.
Bagasse and Bagasse Furnaces.* (11) Feb. 18.
A New Turbine (Bergmann).* (12) Feb. 18; (26) Feb. 18; (73) Feb. 18.
A Two-Hundred-Ton Ice-Making Plant.* (12) Feb. 18.
A Telpherage System for Handling River Traffic.* (14) Feb. 26.
The Wright Injunction (Aeroplanes).* (19) Serial beginning Feb. 19.
Method of Splicing Wire and Other Rope.* J. Watt. (From *Amer. Machinist.*) (16) Feb. 19.
A Recent Comparison of Turbines and Engines. Warren H. Miller. (14) Feb. 19.
Direct Sulphate of Ammonia Manufacture. G. Stanley Cooper. (66) Feb. 22.
Devillers Coal Briquetting Machinery.* Charles H. Hughes. (20) Feb. 24.
The Handling and Storing of Factory Stock, Methods in use at the Plant of the United Shoe Machinery Company.* (20) Feb. 24.
How a Gyroscope Acts.* C. E. Wolff, A. M. Inst. C. E. (47) Feb. 25.
Oxy-Acetylene Welding. H. S. Smith. (29) Feb. 25.
6 000 Horse-Power Hydraulic Absorption Dynamometer.* (62) Feb. 28.
The Penfield Mechanical Brick Setting Machine.* (62) Feb. 28; (76) Feb.
The Development of the Hydraulic Reaction Turbine in America.* H. Birchard Taylor. (9) Mar.
Evaporating Plants on Board Ship. William J. Auken. (95) Mar.
Most Powerful Turbines ever Built.* H. Birchard Taylor. (64) Mar. 1.
Ice Making and Steam Heating by Small Central Station.* (27) Mar. 3.
Motors in Contracting Work.* (27) Mar. 3.
Structural Steel Motor Supports.* George H. Westerman. (27) Mar. 3.
Compressed Air and its Uses.* (20) Serial beginning Mar. 3.
Segregation Phenomena in Steel Castings.* S. S. Knight. (Paper read before the Phil. Foundrymen's Assoc.) (20) Mar. 3.
An Ambitious Scheme of Heat Utilization.* (101) Mar. 5.
The Development of Oil Gas in California.* Edward C. Jones. (Paper read before the Amer. Gas Inst.) (24) Mar. 7.
La Pompe à Gaz Humphrey.* F. Drouin. (33) Nov. 6.
Appareil Sertisseur Semi-Automatique Système Gallon.* (33) Jan. 29.
Les Appareils de Sureté des Chaudières à Vapeur Indicateurs du Niveau de l'Eau. F. Sinigaglia. (37) Jan. 31.
Procédé de Fabrication d'un Gaz d'Eclairage Léger Système Rincker et Wolter. (33) Feb. 5.
Les Amortisseurs d'Automobiles. E. Girardault. (33) Serial beginning Feb. 5.
Appareils de Protection pour les Dégauchisseuses.* Henri Mamy. (33) Feb. 19.
Grands Moteurs à Gaz de Construction Américaine.* (33) Feb. 19.
Uber das Auftreten von Achsialen Drücken Sowie deren Beseitigen bei Zentrifugalpumpen.* Emil Gutman and Ludwig Weil. (53) Serial beginning Dec. 24.
Konstruktion Hydraulischer Sicherheitsventile.* Eduard Müller. (48) Dec. 25.
Sandabsturzbrücken für den Spülversatz der Oberschlesischen Kohlenbergwerke.* Karl Bernhard. (48) Jan. 8.
Ein Graphisches Verfahren zur Ubertragung der Indikatordiagramme von Verbrennungsmaschinen in das Entropiediagramm. V. Maleev. (53) Jan. 14.
Versuche mit einer Schulz-Turbine.* M. F. Gutermuth. (48) Jan. 15.
Untersuchung einer 1 000-pferdigen Dampfturbine der Sächsischen Maschinenfabrik.* E. Josse. (48) Serial beginning Jan. 22.

*Illustrated.

Mechanical—(Continued).

Betriebseinrichtungen und Arbeitsverfahren bei der Deutschen Niles-Werkzeugmaschinenfabrik in Oberschöneweide.* G. Schlesinger. (48) Serial beginning Jan. 29.
Ein Neues Graphisches Verfahren zur Bestimmung der Grössten Stabkräfte im Kranparabelträger.* Hermann Weidemann. (48) Jan. 29.
Versuche an Einem Turbinengebläse der Bauart C. H. Jaeger.* H. Mitter. (48) Feb. 5.

Metallurgical.

The Electrical Reduction of Iron Ore.* Joseph W. Richards. (3) Feb.
Continuous Process for Smelting Iron Ore in the Electric Furnace.* E. R. Taylor. (47) Feb. 4.
Uniformity of Blast Furnace Operation. Jos. W. Richards. (Abstract from *Metallurgical and Chemical Engineering.*) (22) Feb. 11.
Equipment and Practice at Florence, Goldfield Mill.* H. G. Morris. (16) Feb. 12.
The Electrical Production of Iron from Iron Ore.* Lars Yngström. (From Bihang till Jern Kontorets *Annaler.*) (12) Serial beginning Feb. 25.
Horwood Process for Separating Zinc Sulphides.* Donald Clark. (16) Feb. 26.
Elimination of Smelter Fumes.* Leroy A. Palmer. (45) Mar.
Sprague Process for Treating Furnace Gases. C. B. Sprague. (16) Mar. 5.
Sur la Forme Théorique des Courbes de Refroidissement des Mélanges Binaires.* E. Rengade. (93) Feb.
Humidité Uniforme de l'Air Soufflé dans les Hauts-Fourneaux, Expériences Faites aux Usines de Clarence, 1909. Gréville Jones. (93) Feb.

Mining.

Shale-Dust and Coal-Dust Tests at Broxburn.* Robert McLaren and William Clark. (59) Vol. 32.
The Testing of Explosives for Sensitiveness to Shock by the Drophammer Method. H. Kast. (From *Zeit. für das gesamte Schiess- und Sprengstoffenwesen.*) (3) Feb.
Electricity in Mines, Some Practical Considerations. Robert Nelson. (Paper read before the Birmingham Univ. Min. Soc.) (22) Feb. 4.
Determining the Output of a Shaft with a Cylindrical Winding Drum.* A. W. Brown. (Abstract of paper read before the Manchester Geol. Soc.) (22) Feb. 4.
Electrical Installation at Cannock Chase Colliery.* (22) Feb. 4.
The Walker System of Concrete Lining for Pit Shafts.* (22) Feb. 11.
Fence-Gates for Winding-Shaft Cages.* C. A. Crofton. (Abstract of paper read before the North of Eng. Inst. of Min. and Mech. Engrs.) (22) Feb. 11.
A European Electric Colliery Railway.* J. B. Van Brussel. (16) Feb. 12.
Brodsworth Main Collieries.* (22) Feb. 25.
Stoping Methods in Mines of Ducktown Basin.* John Tyssowski. (16) Feb. 26.
Windber Power Plants.* (45) Mar.
Safety Appliances in German Mines.* R. W. Voigt. (45) Mar.
The Primero Disaster.* R. L. Herrick. (45) Mar.
Dredging Nome Beach Sands.* (45) Mar.
Methods and Cost of Sinking the Brier Hill Concrete-Lined Shaft, Michigan.* William Kelley. (Abstract of paper read before the Lake Superior Min. Inst.) (86) Mar. 2.
Tailings Dam of the Cananea Consolidated Copper Company.* L. D. Ricketts. (16) Mar. 5.
The Oliver Continuous Filter at Minas del Tajo.* G. A. Tweedy and R. L. Beals. (16) Mar. 5.
Stationary versus Moving Hoisting Plants. J. F. Jackson. (16) Mar. 5.

Miscellaneous.

The Testing of Explosives for Sensitiveness to Shock by the Drophammer Method. H. Kast. (From *Zeit. für das gesamte Schiess- und Sprengstoffenwesen.*) (3) Feb.
Recent Progress in Industrial Pyrometry.* Chas. R. Darling. (12) Feb. 11.
Methods and Cost of Hydraulic Filling at Cairo, Ill.* Jean M. Allen. (86) Feb. 16.
Théorie Elémentaire des Abaques à Transversales.* G. Schoofs. (30) Feb.

Municipal.

English Methods of Using Tar as a Binder in Macadam Road Construction.* (86) Jan. 16.
Notes on the Construction of Macadam Pavements and a Table Showing the Amount of Stone Required. George B. Pike. (86) Feb. 9.
Paving Along Street Railway Tracks. Thos. B. McMath. (Abstract of paper read before the Central Elec. Ry. Assoc.) (86) Feb. 9.

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*Illustrated.

Municipal—(Continued).

Formulas for Sidewalk Construction used by the Bureau of Sidewalks of Chicago, Ill. N. E. Murray. (Abstract of paper read before the Ill. Soc. of Engrs. and Surv.) (86) Feb. 9; (13) Feb. 17.
Work of the Municipal Asphalt Plant of San Francisco in 1909. (86) Feb. 16.
Summary of Tests made at New York City of Machines for Cleaning Streets by the Use of Water. (86) Feb. 23.
Proposed Standard Specifications for Portland Cement Curb and Gutter.* (Report of Committee to National Assoc. of Cement Users.) (86) Feb. 23.
An Experimental Road Surfacing of 2-in. Concrete Cubes.* J. Y. McClintock and George C. Wright. (Paper read before the National Assoc. of Cement Users.) (13) Mar. 3; (86) Mar. 2; (14) Mar. 5.
Economics and Principles of Macadam Construction for Towns.* D. T. Black. (96) Mar. 4.
Municipal Asphalt Plant, Kansas City, Mo.* (14) Mar. 5.

Railroads.

Automatic Electric Railway Signals.* L. Frederic Howard. (98) Dec.
Brake Manipulation and Operation in General Freight Service, with a Review of Some of the Causes and Conditions which Produce Shocks and Break-in-Twos.* W. V. Turner. (61) Dec. 21.
Report on the Question of Electric Traction. (Subject for Discussion at the 8th Sess. of the Ry. Cong.)* George Gibbs. (88) Jan.
Report on the Question of Operation of Switches and Signals. (Subject for Discussion at the 8th Sess. of the Ry. Cong.) Ulbricht. (88) Jan.
Report on the Question of Transshipment. (Subject for Discussion at the 8th Sess. of the Ry. Cong.)* C. de Burlet. (88) Jan.
Electrification of the Bavarian State Railways.* J. Jacqmin. (88) Jan.
The New Wustermark Shunting Yard.* (From *Zeit. d. Vereins deutsch. Eisenbahnverwaltung.*) (88) Jan.
The Transcontinental Railway Survey of Australia. (12) Feb. 4.
Area of Contact between Car Wheels and Rails.* E. L. Hancock. (13) Feb. 10.
Track Elevation at Evanston, Ill.; Chicago, Milwaukee & St. Paul Ry.* E. O. Greifenhagen. (13) Feb. 10.
Tractive Power of Locomotives.* William N. Allman. (15) Feb. 11.
Steel Box Car for the Union Pacific.* (15) Feb. 11.
New Locomotives for the Chicago Great Western.* (15) Feb. 11.
The New Panama Railroad. R. F. Hoffmark. (From *Purdue Engineering Review.*) (15) Feb. 11.
Mechanical Handling of Freight at Transfer Stations. H. McL. Harding. (18) Feb. 12.
New Consolidation Locomotive of the Lehigh Valley R. R.* (18) Feb. 12.
A Combination Steel and Concrete Tie on the Pittsburg, Fort Wayne & Chicago Ry.* (13) Feb. 17.
Two Foreign Developments in Railway Ties.* (13) Feb. 17.
The Design of the Stations on the Evanston Track Elevation Work; C., M. & St. P. Ry.* E. O. Greifenhagen. (13) Feb. 17.
The Electrification of Trunk Lines. L. R. Pomeroy. (Abstract of paper read before the Eng. Soc. of Columbia Univ.) (15) Feb. 18.
Colfax Grade Revision; Southern Pacific.* Bradford Boardman. (15) Feb. 18.
Valuation of Railways in Washington. J. C. Lawrence. (15) Feb. 18.
Mallet Articulated Compound Locomotive for the Colombia National.* (15) Feb. 18.
The Bellinzona-Mesocco 1 500-Volt Railway.* (17) Feb. 19.
New Type of Overhead Construction, N. Y., N. H. & H. R. R.* (18) Feb. 19; (46) Feb. 12.
Mogul Locomotives for the Tientsin-Pukow Ry., China.* (18) Feb. 19; (15) Mar. 4.
Fuel Economy on Testing Plants and Railways. H. H. Vaughan. (Abstract of paper read before the Western Canada Ry. Club.) (18) Feb. 19.
Mallet Compound Locomotive for the Central South African Railways.* (18) Feb. 19.
Some Notes on Specifications for Earthwork in Railway Construction. James H. Bacon. (Abstract of paper read before the Amer. Soc. of Eng. Contrs.) (86) Feb. 23.
Proposed Rearrangement of Railway Terminals in Chicago.* (13) Feb. 24.
Eight-Wheel Engines with Superheaters for the Western Railway of Havana.* (15) Feb. 25.
Copper and Steel for Locomotive Fire Boxes. H. B. Lake. (Abstract of paper read before the Western Canada Ry. Club.) (18) Feb. 26.
Terryville Tunnel, New York, New Haven & Hartford Railroad.* (14) Feb. 26.
A Combined Concrete Fence and Retaining Wall.* (14) Feb. 26.
The Experimental Catenary Line of the Connecticut Company.* (17) Feb. 26.

*Illustrated.

Railroads—(Continued).

Method of Laying Concrete under Water using a Tremie; Detroit River Tunnel. Olaf Hoff. (Paper read before the National Assoc. of Cement Users.) (86) Mar. 2.
Economical Freight Transference at Railway Terminals and Shipping Docks.* H. McL. Harding. (13) Mar. 3.
The Hudson Bay Railway Project.* (13) Mar. 3.
High-Voltage Direct-Current Equipment for Washington, Baltimore & Annapolis Railway.* (27) Mar. 3; (13) Mar. 3; (17) Mar. 5.
Electrical Plant of the Hudson and Manhattan Railroad Company.* (27) Mar. 3.
Equipment Depreciation and Renewal. William Mahl. (15) Mar. 4.
Track Construction in the Detroit River Tunnel.* (14) Mar. 5.
Power Station of the Hudson & Manhattan Railroad.* Hugh Hazleton. (17) Mar. 5.
Improvements in European Catenary Work.* (17) Mar. 5.
Note sur les Perfectionnements Apportés au Système d'Allumage Instantané des Trains Eclairés à l'Incandescence par le Gaz en Essai à la Compagnie des Chemins de Fer de l'Est.* E. Biard and G. Mauclère. (38) Feb.
Les Locomotives Compound à Grande Vitesse à Trois Essieux Couplés et à Roues Motrices de 1m, 900 de la Compagnie Royale des Chemins de Fer Portugais.* Henri Lavialle d'Anglards. (38) Feb.
Le Funiculaire de l'Ile de Capri (Italie).* M. Bousquet. (33) Feb. 5.
Die Form der Winkelstützmauern aus Eisenbeton mit Rücksicht auf Bodenruck und Reibung in der Fundamentfuge.* Albert Klein. (78) Dec. 16.
Ergebnisse der Versuchsfahrten mit der 4/5-Gekuppelten Verbund-Güterzuglokomotive Gruppe 730 der Italienischen Staatsbahn.* G. Heise. (48) Jan. 22.
Die Verminderung der Höchststeigung in Tunneln der Gebirgsbahnen. R. Sanzin. (48) Jan. 29.

Railroads, Street.

Signal Improvements on the District and Tube Railways.* (21) Feb.
Permanent Way of Tube Railways.* (21) Serial beginning Feb.
Street Car Vacuum Ventilation.* (101) Feb. 12.
Trailer Motor Cars in Philadelphia.* (17) Feb. 26.
New Substation Equipment of the Boston Elevated Railway Company.* (17) Mar. 5.
Die Elektrische Lokalbahn Trient-Malè und die Neuen Elektrizitätswerksanlagen der Stadtgemeinde Trient.* Paul Dittes. (53) Serial beginning Jan. 28.

Sanitation.

The Disposal of Sewage. F. Herbert Snow. (98) Dec.
A Method of Determining the Sizes of the Pipes of a Hot-Water Apparatus.* J. Jeffreys. (70) Feb.
Sewer Pipe Data. (76) Feb.
Cement Tile Investigation. (76) Feb.
The Collection and Disposal of Refuse in the City of Boston, Mass.* (13) Feb. 10.
The Sewerage Problem of Greater Pittsburgh. (14) Feb. 12; (13) Feb. 10.
Standards for Sewage Effluents. John C. Thresh. (Abstract of paper read before the Assoc. of Mgrs. of Sewage Disposal Works of Eng.) (14) Feb. 12.
The Design of Small Intermittent Filters. Paul Hanson. (Abstract of paper read before the Ohio Eng. Soc.) (14) Feb. 19.
Purification of Sewage for Power Plant Purposes.* (14) Feb. 19.
The Protection and Drainage of Lands Subject to Overflow. (14) Feb. 26.
Refuse Disposal in Marseilles. (14) Feb. 26.
Portable Shower Baths in Baltimore.* (101) Feb. 26.
Heating and Ventilating Minnesota Schools.* (101) Feb. 26.
Epuration des Eaux d'Egout, Système Imhoff.* (35) Feb.

Structural.

A Modern Boiler Shop.* E. R. Fish. (Paper read before the Engrs.' Club of St. Louis.) (1) Dec.
The Work of the Clay Products Section of the Technologic Branch, United States Geological Survey.* A. V. Bleininger. (58) Jan.
The Hardening of Hydraulic Cements. G. Becker. (Abstract from *Tonindustrie Zeitung.*) (67) Feb.
Weber Reinforced Concrete Chimneys.* (20) Feb. 10.
Fire Protection in San Francisco under the New Building Law. (13) Feb. 10.
A Pneumatic Cushion Cap for Driving Reinforced Concrete Piles.* (86) Feb. 16.
Concrete Pile Foundations for the Evansville Filters.* F. H. Stephenson. (14) Feb. 19.
An Unusual Factory Floor. (14) Feb. 19.

*Illustrated.

Structural—(Continued).

Experiments on the Coarser Particles in Cement.* George Sydney Binckley. (14) Feb. 19.
Tests of Concrete Columns made Under Building Conditions.* H. C. Berry. (14) Feb. 19.
Design of Retaining Walls for the Steptoe Smelter.* S. Severin Sörensen. (14) Feb. 19.
What Consideration Should be Given to Continuity in Reinforced Concrete Beams and Slabs?* M. E. Thomas. (86) Feb. 23.
Proportioning Latticed Columns by Weight per Foot.* Benton Lattin. (13) Feb. 24.
Shrinking and Tempering Shop for Guns at Woolwich Arsenal.* (11) Feb. 25.
A Water Tank with a Dome Supported Bottom.* (14) Feb. 26.
The Use of Miniature Excavating Buckets.* (14) Feb. 26.
Demolition of the Old Union Station at Worcester.* C. H. Gilman. (14) Feb. 26.
Industrial Applications of Reinforced Concrete.* M. M. Sloan. (9) Mar.
A Method of Long Span Light Floor Construction, with Comparative Costs.* Emile G. Perrot. (Paper read before the National Assoc. of Cement Users.) (86) Mar. 2; (14) Mar. 5.
A Simple Method of Testing Damp Proofing Materials. Cloyd M. Chapman. (Abstract of paper read before the National Assoc. of Cement Users.) (14) Mar. 5.
Constructing a Building Above an Underground Station.* (14) Mar. 5.
A Twelve-Story Concrete Building without Interior Columns.* W. P. Anderson. (14) Mar. 5.
Standard Building Regulations for the Use of Reinforced Concrete. (National Assoc. of Cement Users.) (14) Mar. 5.
Tests of Reinforced Concrete Columns.* Peter Gillespie. (Paper read before the National Assoc. of Cement Users.) (14) Mar. 5.
L'Avenir du Béton non Armé. N. de Tedesco. (84) Serial beginning Jan.
Essais Comparatifs de Flexion Statique et Dynamique sur Barreaux Entaillés.* A. Léon et P. Ludwik. (From *Oesterr. Wochenschrift für den öffentlichen Baudienst.*) (93) Feb.
Résistance des Pieux pour Pilotis. M. Tjaden. (Abstract from *De Ingenieure.*) (35) Feb.
De la Résistance des Pièces Rivées.* Ch. Frémont. (93) Feb.
Belastungsversuche mit Gekreuztbewehrten Eisenbetondecken.* (78) Dec. 16.
Das Verhalten Hydraulischer Bindemittel im Seewasser.* H. Burchartz. (78) Dec. 16.
Vergleichende Festigkeitsversuche an Körpern aus Zementmörtel. M. Grübler. (48) Dec. 25.
Neuere Fortschritte in der Zement-, Kalk-, Phosphat-, and Kaliindustrie.* C. Naske. (48) Serial beginning Jan. 1.
Der Luftwiderstand auf Grund der Neueren Versuche.* W. Schüle. (48) Serial beginning Jan. 1.
Schiessstandsanlagen in Eisenbetonkonstruktion in Holtenau bei Kiel.* Jos. Gaugusch. (78) Jan. 7.
Betonzerstörung durch Schwefelwasserstoffgas. Erich Stephan. (78) Jan. 7.

Topographical.

An Instrument for Measuring and Recording Tunnel Sections.* (13) Mar. 3.

Water Supply.

Method of Making Watertight by Grouting the Yonkers Pressure Tunnel (Siphon) of the Catskill Aqueduct.* (86) Feb. 9.
The Type Characteristic of Impulse Wheels and its Use in Design.* S. J. Zowski. (13) Feb. 10.
Steel Penstocks.* R. A. Wright. (13) Feb. 10.
Sterilization of the Connecticut River Water. (14) Feb. 12.
Construction of Reinforced-Concrete Dam at Fredericksburg.* (14) Feb. 12.
The Albelda Reinforced-Concrete Siphon for a 97-ft. Head, Tuena, Spain.* B. A. Etcheverry. (From the *Cal. Jour. of Tech.*) (13) Feb. 17; (96) Feb. 25.
Pumping Stations of the Minidoka Irrigation Project.* (14) Feb. 19.
The Steel Pipe Lines and River Crossings, Little River Water Supply, Springfield, Mass.* (14) Feb. 19.
Preliminary Work on the Barren Jack Reservoir. (14) Feb. 19.
Reinforced Concrete Aqueduct Lining.* H. E. Reeves. (Abstract of paper read before the Ill. Soc. of Engrs. and Survs.) (13) Feb. 24.
Notes on Some Errors of Fluid Differential Gages.* Geo. Jacob Davis, Jr., Assoc. M. Am. Soc. C. E. (13) Feb. 24.
Designs for Hydraulic Power Plants Subject to Reduced Head during High Water.* (13) Feb. 24.

*Illustrated.

Water Supply—(Continued).

Steam-Driven Pumping Plant for Deep Wells and Bore-Holes.* Alfred Towler, M. I. Mech. E. (Paper read before the Assoc. of Water Engrs.) (11) Feb. 25.
Braintree Waterworks Extensions. (12) Feb. 25.
The Discharge of a 12-Foot Wood Stave Pipe.* H. H. Cochrane. (14) Feb. 26.
Evaluation of Water Rights.* Arthur Halsted. (14) Feb. 26.
Some Notes and Figures on the Valuation of the Water Works Plant at Richmond, Ind. Howard A. Dill. (Abstract of paper read before the Ind. San. and Water Supply Assoc.) (86) Mar. 2.
Structural Features of a 24-Mile Steel Pipe Line for the Portland, Ore., Waterworks.* (86) Mar. 2.
The Influence of Forests on Climate and on Floods. Willis L. Moore. (Abstract of Report to U. S. House of Representatives.) (13) Mar. 3.
Description of the New Dam and Pumping Station Built by the City of Peterborough, Ont.* A. W. Ellson Fawkes. (96) Mar. 4.
The Water Supply System for the Central of Georgia Railway's Macon Shops.* (96) Mar. 4.
Feather River Hydro-Electric Plant, Great Western Power Co.* (18) Mar. 5.
Die Wasserkraftsanlage im süden der Stadt München.* J. Bosch. (78) Serial beginning Dec. 16.

Waterways.

Methods of Constructing and Driving Combination Concrete and Timber Piles with Some Results of Tests.* (86) Feb. 9.
The Panama Canal.* George W. Goethals. (Paper read before the Brit. Assoc.) (11) Serial beginning Feb. 11.
Some Practical Views as to Transportation on Western Rivers.* Thomas P. Roberts. (13) Feb. 17.
Paxton Creek Flood Controlling Works, Harrisburg, Pennsylvania.* R. M. Riegel. (From *Cornell Civ. Engr.*) (13) Feb. 17.
Some Notes in Connection with the Construction of a Concrete Dam on the Trent Canal.* J. B. Brophy, M. C. Soc. C. E. (96) Feb. 18.
The Sea Wall in Connection with Buildings.* George A. Orrok. (Paper read before the Conn. Soc. of Civ. Engrs.) (14) Feb. 26.
The Locks and Gates of the Panama Canal.* (14) Feb. 26.
Fighting the Paris Flood.* Warren H. Miller. (14) Feb. 26.
The Protection of Submarine Structures.* W. A. Jones. (9) Mar.
Method of Laying Concrete under Water using a Tremie; Detroit River Tunnel. Olaf Hoff. (Paper read before the National Assoc. of Cement Users.) (86) Mar. 2.
The Influence of Forests on Climate and on Floods. Willis L. Moore. (Abstract of Report to U. S. House of Representatives.) (13) Mar. 3.
The Efficiency and Cost of Concrete for the Preservation of Piles Exposed in Sea Water. C. C. Horton. (Paper read before the National Assoc. of Cement Users.) (13) Mar. 3.
Les Moyens de Communication entre la Deux Rives de l'Escaut, à Anvers.* R. v. d. Mensbrugghe. (31) 1909, Pt. 3.
Le Projet de Port de San Antonio (Chili).* (From *De Ingenieur.*) (31) 1909, Pt. 3.
Le port de Mostaganem (Algérie).* P. Caufourier. (33) Nov. 6.
Discussions en Allemagne Concernant les Dimensions des Bateaux auxquels doit Livrer Passage le Canal du Rhin au Wéser à Elbe. (30) Feb.
La Crue de la Seine, de Janvier, 1910.* A. Dumas. (33) Feb. 5.
Bootsmagazin auf der Kaiserlichen Werft zu Danzig.* Röhlke. (78) Serial beginning Dec. 16.

*Illustrated.

Vol. XXXVI. MARCH, 1910. No. 3.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

CONTENTS

PLATES

Vol. XXXVI. MARCH, 1910. No. 3.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

PAPERS AND DISCUSSIONS

This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD: THE SITE OF THE TERMINAL STATION.

By George C. Clarke, M. Am. Soc. C. E.

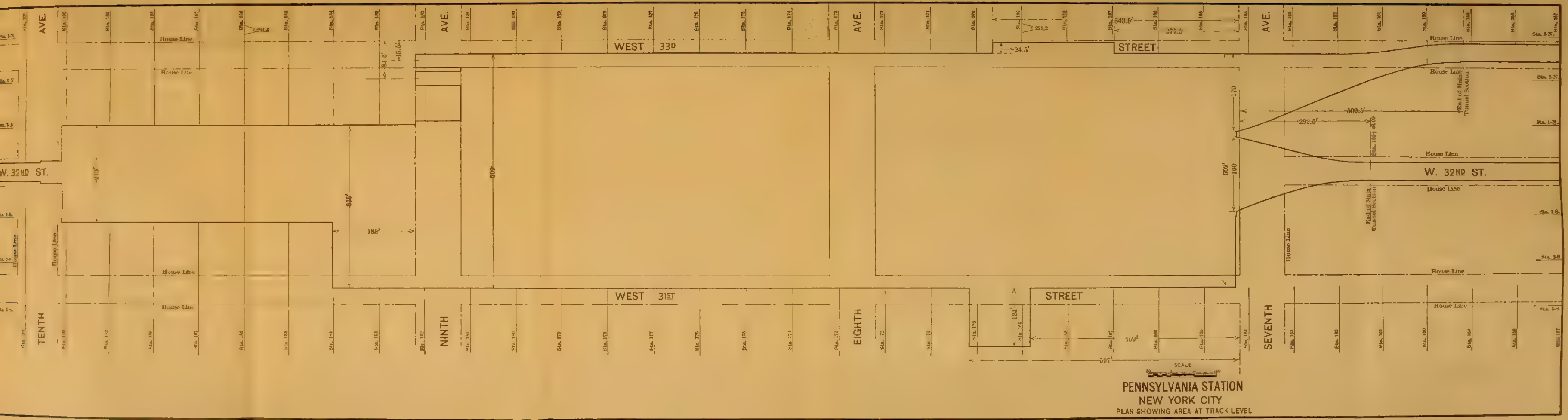
To be Presented May 4th, 1910.

The purpose of this paper is to describe the preliminary work for and the preparation of that portion of the site, for the Terminal Station in Manhattan, of the New York Tunnel Extension of the Pennsylvania Railroad, which was constructed under the direction of the Chief Engineer of the East River Division, including the disposal of material excavated from all parts of the Terminal construction and the tunnels on the East River Division.

As outlined in the paper by Brigadier-General Charles W. Raymond, M. Am. Soc. C. E., Chairman of the Board of Engineers, the track yard of the station, Plate LXVI, extends from the east line of Tenth Avenue eastward to points in 32d and 33d Streets, respectively, 292 and 502 ft. east of the west line of Seventh Avenue. The width of the available area at track level at Tenth Avenue is 213 ft., continuing at this width to within 182 ft. of the west line of Ninth Avenue, where, by an offset toward the south, it is increased to 355 ft. This width is held to a point 5 ft. east of the east line of Ninth Avenue, where, by an offset toward the north, it is increased to 509 ft., which width continues to the west line of Seventh Avenue, where it divides

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

PLATE LXVI.
PAPERS, AM. SOC. C. E.
MARCH, 1910.
CLARKE ON
THE SITE OF THE TERMINAL STATION:
PENNSYLVANIA RAILROAD.



PENNSYLVANIA STATION
NEW YORK CITY
PLAN SHOWING AREA AT TRACK LEVEL

into two fan-shaped areas. The north area has a width of about 170 ft. and the south one, 160 ft., at the house line, each area tapering gradually to the width of the standard three-track tunnel at the east ends, noted above in 33d and 32d Streets. Additional track room for four tail-tracks is gained by the construction of two double-track tunnels under Ninth Avenue at 33d Street, their center lines being parallel to the street and 45.5 and 84.5 ft. distant, respectively, from the north house line. An additional width of 24.5 ft. is occupied on the north from 277.5 ft. to 543.5 ft. west of the west line of Seventh Avenue, where the buildings on the north side of 33d Street have been torn down and the enclosing wall set back in anticipation of a future outlet to 34th Street; and on the south, from 459 ft. to 597 ft. west of the west line of Seventh Avenue a rectangular offset of 124 ft. encloses the area occupied by the Service Building. The total area above outlined is the space occupied at track level, and amounts to 28 acres, of which the portion west of the east house line of Ninth Avenue and south of a line 107.3 ft. south of the south line of 33d Street is a part of the North River Division, and was constructed under the direction of the engineers of that Division; the fan-shaped areas east of the west house line of Seventh Avenue were constructed under the direction of the Chief Engineer of Electric Traction and Terminal Station Construction.

In June, 1903, when the writer's connection with the work began, the preliminary surveys had been completed and the location and extent of the Terminal track area had been fixed, in so far as the city blocks to be occupied were concerned. This contemplated area, however, did not include the portion between Ninth and Tenth Avenues, that being added subsequently. The elevation of the track level had also been fixed by the requirement in the agreement with the City that no part of the permanent structure should approach within 19 ft. of the surface under any avenue or under any street except within the Terminal area. The nearest approach of the tracks to the surface is at a point 320 ft. east of Eighth Avenue, where the top of the rail is 40 ft. below the 31st Street curb line.

Wash-Borings.

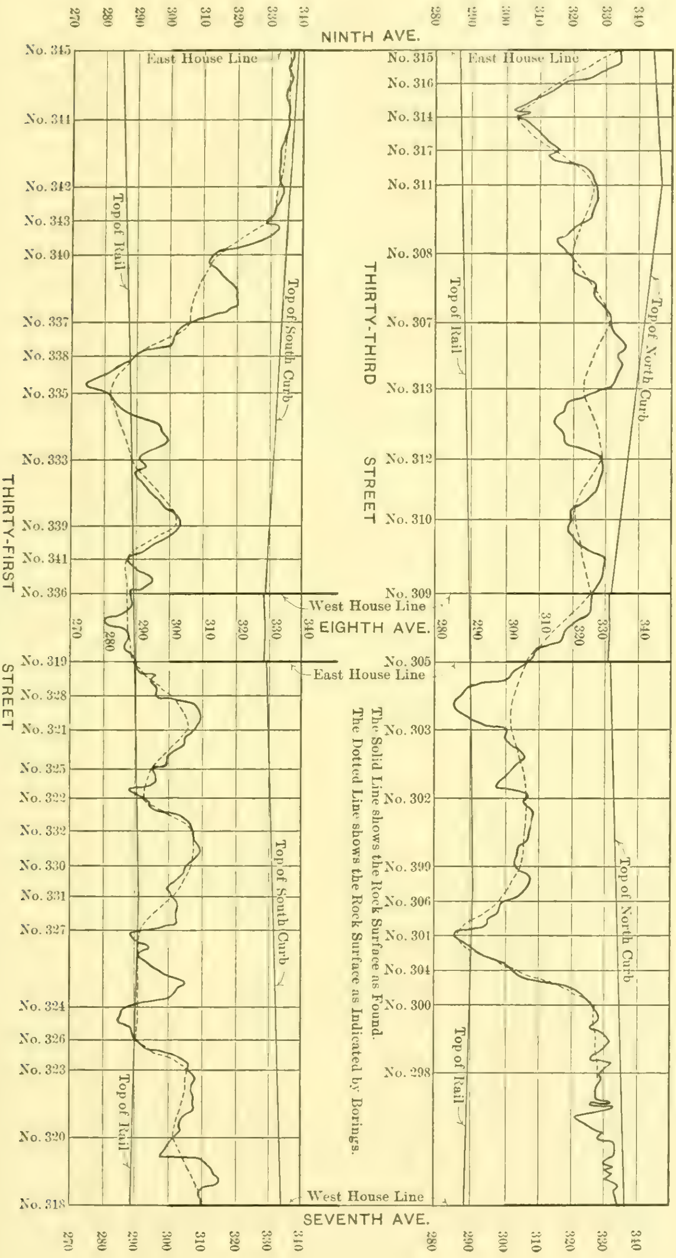
The general plan of enclosing the area in retaining walls having been adopted, wash-borings were taken, for the purpose of determining the best location for the walls, the depth of rock, and the nature of

the material overlying it. These borings were made along both curb lines of Seventh Avenue, the east curb line of Ninth Avenue, the north curb line of 33d Street, and the south curb line of 31st Street. The borings, as a rule, were taken at intervals of approximately 100 ft., some deviation in these intervals being made in order to prevent injury to water, gas, and sewer connections, and, if the elevation of the surface of the rock, as determined by one of these borings, corresponded fairly well with the borings on either side of it, no intermediate borings were taken. When a discrepancy appeared, a boring was taken midway between the two non-corresponding ones, and if the information obtained from the intermediate boring failed to account for the discrepancy, others were taken at the quarter points of the original 100-ft. interval.

The dotted lines on Fig. 1 show the profiles of the surface of the rock underlying 31st and 33d Streets, on the line of the borings, constructed from the elevations obtained by them; the solid lines show the profiles of the actual surface of the rock as found when uncovered. It will be noted that, except in three cases, Borings 313, 328, and 333, the two profiles correspond very closely at the points where the borings were made, but they differ widely between those points, a variation of 5 ft. being common; there is a variation of 14 ft. between Borings 324 and 327, and between Nos. 337 and 340; and of 12 ft. between Nos. 333 and 335, and between Nos. 312 and 313, while an extreme variation of 17 ft. is shown between Nos. 303 and 305. At each of the points where the variation is great the interval between borings is the full 100 ft., and it is quite apparent that, if a definite idea is to be obtained of the elevation of the surface of the rock in Manhattan, borings must be taken at shorter intervals.

The necessary width of trench for the construction of the retaining walls was determined by the elevation of the rock, as shown by the borings, and only in the case of the dip between Borings 303 and 305 did the variation lead to any difficulty. The trench at that point had to be widened after rock was reached. This depression corresponded very closely in location to that of one arm of the creek shown on General Viele's map of 1865,* the bed of that stream, or one in ap-

* Reproduced as Plate LXI in the paper by Mr. Noble.



PROFILE OF ROCK SURFACES IN THIRTY-FIRST AND THIRTY-THIRD STREETS, BETWEEN SEVENTH AND NINTH AVENUES.

FIG. 1

proximately the same location, being clearly marked across the excavation by smoothly-worn rock and well-rounded boulders. The original stream, however, seemed to have turned in a westerly direction under 31st Street to Eighth Avenue instead of crossing, as shown on General Viele's map.

Sewers.

The arrangement of the sewers in the streets in the vicinity of the Terminal Site, previous to the beginning of the construction, and the drainage area tributary to those sewers, is shown by Fig. 2. The main sewer for this district was in Eighth Avenue, and was a 6-ft. circular brick conduit within the Terminal area. The sewers leading to it from the west, in 31st, 32d, and 33d Streets, were elliptical, 3 by 2 ft., and egg-shaped, 4 ft. by 2 ft. 8 in., although in no case did they drain more than one block, and they were on a heavy grade. Draining into Eighth Avenue from the east, the one on 31st Street was 4 ft. by 2 ft. 8 in., egg-shaped, and drained a length of two blocks, and those on 32d and 33d Streets were circular, 4 ft. in diameter, and drained the territory for three blocks, or as far east as Fifth Avenue. There were no sewers in Seventh Avenue within the Terminal area, except small vitrified pipes, each less than 200 ft. in length.

It was desirable that the size and number of the sewers in the streets and avenues surrounding the Terminal should be reduced to a minimum, on account of the difficulty of caring for them during construction and also to reduce the probability of sewage leaking into the underground portion of the work after its completion. With this in view, the plan was adopted of building an intercepting sewer down Seventh Avenue from north of 33d Street to the 30th Street sewer, which, being a 4-ft. circular conduit, was sufficiently large to carry all the sewage coming from east of Seventh Avenue and south of 34th Street. It was decided to build this sewer of cast iron, where it crossed the proposed construction work, and also to replace with cast iron the brick sewers on 31st, 32d, and 33d Streets from Seventh Avenue to a point east of the west end of the standard tunnel section, and also the sewer on Eighth Avenue from the north side of 33d Street to the south side of 31st Street. This arrangement permitted: first, the removal of the sewer in 32d Street between Seventh and Eighth Avenues, which was necessary, as that street was to be excavated; second, the reduction of the sewer in Eighth Avenue from a

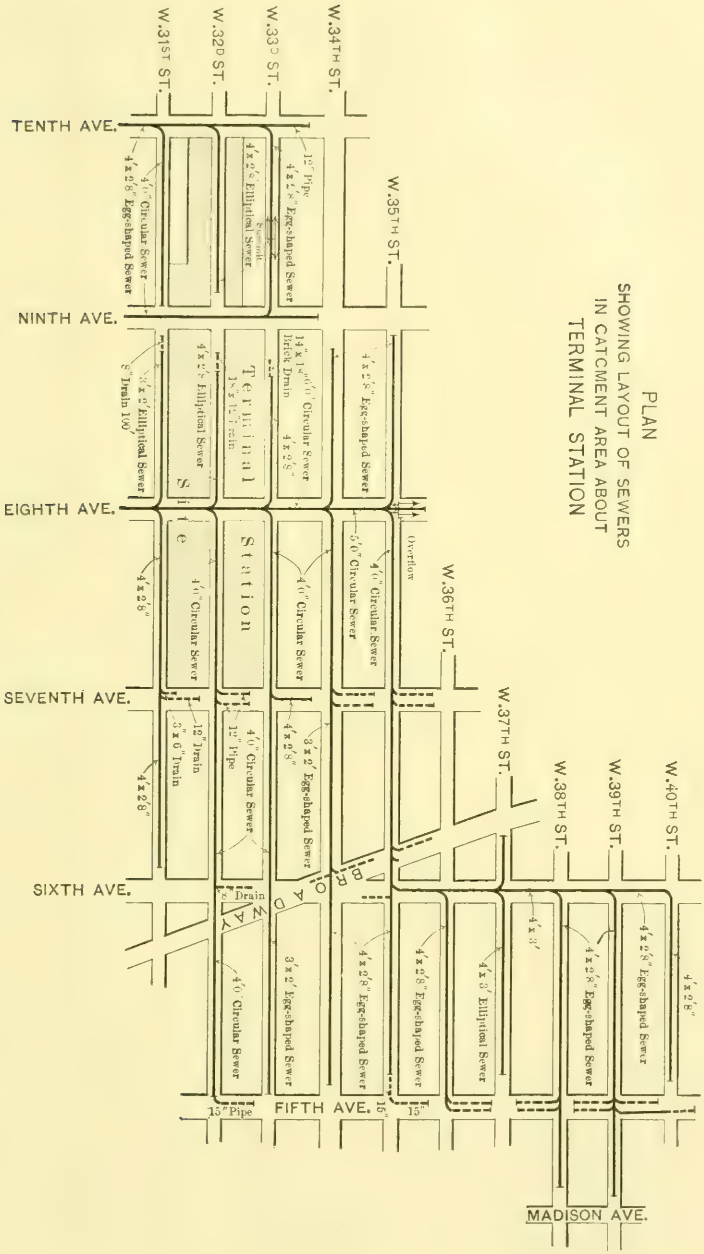

PLAN
SHOWING LAYOUT OF SEWERS
IN CATCHMENT AREA ABOUT
TERMINAL STATION
TENTH AVE.
NINTH AVE.
EIGHTH AVE.
SEVENTH AVE.
SIXTH AVE.
FIFTH AVE.
MADISON AVE.
W.31ST ST.
W.32D ST.
W.33D ST.
W.34TH ST.
W.35TH ST.
W.36TH ST.
W.37TH ST.
W.38TH ST.
W.39TH ST.
W.40TH ST.
BROADWAY
Terminal Station Site
4′0″ Circular Sewer
4′x2′8″ Egg-shaped Sewer
4′x2′8″ Elliptical Sewer
12″ Pipe
3′x2′ Elliptical Sewer
8″ Drain 100′
4′x2′8″ Elliptical Sewer
14″x18″ Brick Drain
5′0″ Circular Sewer
Overflow
12″ Drain
3′x6″ Drain
3′x2′ Egg-shaped Sewer
8″ Drain
4′x3′ Elliptical Sewer
4′x3′
15″ Pipe
15″

FIG. 2.

6-ft. to a 5-ft. circular conduit; and, third, assuming that the sewage and drainage from the Terminal would be pumped directly to the sewers in the avenues, the reduction of the sewers in 31st and 33d Streets, from Seventh to Ninth Avenue, to 15-in. vitrified pipes, except west of the Service Building in 31st Street, to accommodate which section, a larger sewer was required. The sewer in 32d Street, from Ninth to Eighth Avenue, of course, could be dispensed with in any arrangement, as all the area tributary to it was to be excavated.

Gas and Water Mains.

A rearrangement of the gas pipes in the three streets crossing the Terminal site was necessary. These pipes were of two classes: trunk mains and service mains. Fortunately, there were but two trunk mains in the three streets, one a 20-in. in 31st Street from east of Seventh Avenue to Ninth Avenue, the other a 16-in. in 32d Street from east of Seventh Avenue to Eighth Avenue. The 20-in. main was relaid from Seventh Avenue and 31st Street down Seventh Avenue to 30th Street and through that street to Ninth Avenue. The 16-in. main was relaid from Seventh Avenue and 32d Street north to 34th Street and through that street to Eighth Avenue. The service mains in 32d Street were no longer required, and were taken up and not replaced. The houses on 31st and 33d Streets were provided with service by two 6-in. wrought-iron mains back of the retaining walls in each street, that location being chosen to avoid damage by gas drip to the water-proofing of the street bridges. As the permanent structures under the avenues were not to approach the surface nearer than 19 ft., only slight rearrangements, sufficient to permit the new sewers and water lines to be laid, were necessary.

There were no large water mains to be cared for, in fact, those in the streets were too small for ample fire protection, being only 6 in. in diameter. The main in 32d Street was taken up and not replaced, and those on 31st and 33d Streets were replaced by 12-in. pipes laid back of the retaining walls. No changes were necessary in the mains, in the avenues, but, before approving the rearrangement for the streets, the Department of Water Supply, Gas and Electricity added a 48-in. main in Eighth Avenue to be laid as a part of this construction, the pipe being supplied by the City.

Location and Design of Retaining Walls.

The plans, from the earliest stages, contemplated founding the retaining wall on the surface of the rock, where of suitable quality, and afterward excavating the rock in front of the toe of the wall to sub-grade. This plan was definitely adopted soon after the borings were completed, on account of the great danger of blasting out large quantities of rock in timbered trenches close to buildings founded on soft material, and also to avoid the additional cost and delay that would have been caused by carrying the walls to sub-grade. The retaining walls in Seventh Avenue, south of the viaduct, and in Ninth Avenue, north of the viaduct, were not governed by the same conditions as in the streets. The dip and quality of the rock at both points required that the walls be carried to sub-grade, and they are, in fact, face walls; the Ninth Avenue wall, in particular, having little thrust to retain, is very light.

The results aimed at in the design and location of the retaining walls in 31st and 33d Streets were:

First.—A perfectly stable wall under all conditions that might reasonably be expected;

Second.—As much room as possible at the elevation of the top of the rail;

Third.—The least necessary interference with adjoining property during construction; and,

Fourth.—The most economical wall that would fulfill the other conditions.

As stated in the paper by Alfred Noble, Past-President, Am. Soc. C. E., the third stipulation required the relinquishing of a portion of the space under these streets granted by the City, but it was finally decided not to approach the south house line of 31st Street with the back of the walls nearer than 9 ft., while on 33d Street the extreme position of the back was fixed at the north line, as there were no buildings, except those belonging to the Railroad Company, on the house line at the low points in the rock.

The assumptions made in designing the wall were as follows:

First.—Weight of concrete, 140 lb. per cu. ft.

Second.—Weight of material from the surface of the ground to a depth of 12 ft. (which was shown by tests made in bore-holes

to be the elevation of the ground-water surface), 100 lb. per cu. ft.; and angle of repose, 30 degrees. The distance of 12 ft. below the surface was the depth of the inverts of the sewers, which undoubtedly drained the ground above them, thus accounting for the standing of the ground-water in planes practically parallel with the surface.

Third.—Weight of buildings back of wall neglected, as that of the present type will about equal the cellars filled with material at 100 lb. per cu. ft., and if large buildings are erected in the future they will undoubtedly be carried to rock.

Fourth.—Reaction from superstructure, live and dead load, 20 000 lb. per lin. ft. of wall.

Fifth.—Weight of materials below the 12-ft. line, 124 lb. per cu. ft., ascertained as follows: The material was considered as weighing 165 lb. per cu. ft. in the solid, and having 40% of voids filled with water at 62.5 lb. per cu. ft., the resulting weight being $\left(165 \times \frac{60}{100}\right) + \left(62.5 \times \frac{40}{100}\right) = 124$ lb. per cu. ft.

Various angles of repose were used for this material in the investigation, and it was finally decided that 30° was the greatest angle that could be expected, whereas the worst condition that could be anticipated was that the sand and water would act separately and give a pressure as follows:

Hydraulic pressure from liquid weighing 62.5 lb. per cu. ft. plus pressure from sand with angle of repose at 30° and weight as follows:

$$\text{Weight of 1 cu. ft. in air} = 165 \times \frac{60}{100} = 99 \text{ lb.}$$

$$\text{Weight of water displaced by 1 cu. ft.} = \frac{60}{100} \times 62.5 \text{ lb.} = 37.5 \text{ lb.}$$

Weight in water, therefore = 61.5 lb. per cu. ft.

These combined weights, of course, are equal to the weight of the combined material in the previous assumption.

Sixth.—The usual requirement that the resultant of both horizontal and vertical forces should, at all points, fall within the middle third of the wall, or, in other words, that there should be no tension in the concrete.

With these assumptions, investigation was made of walls with various batters and differently designed backs. This investigation de-

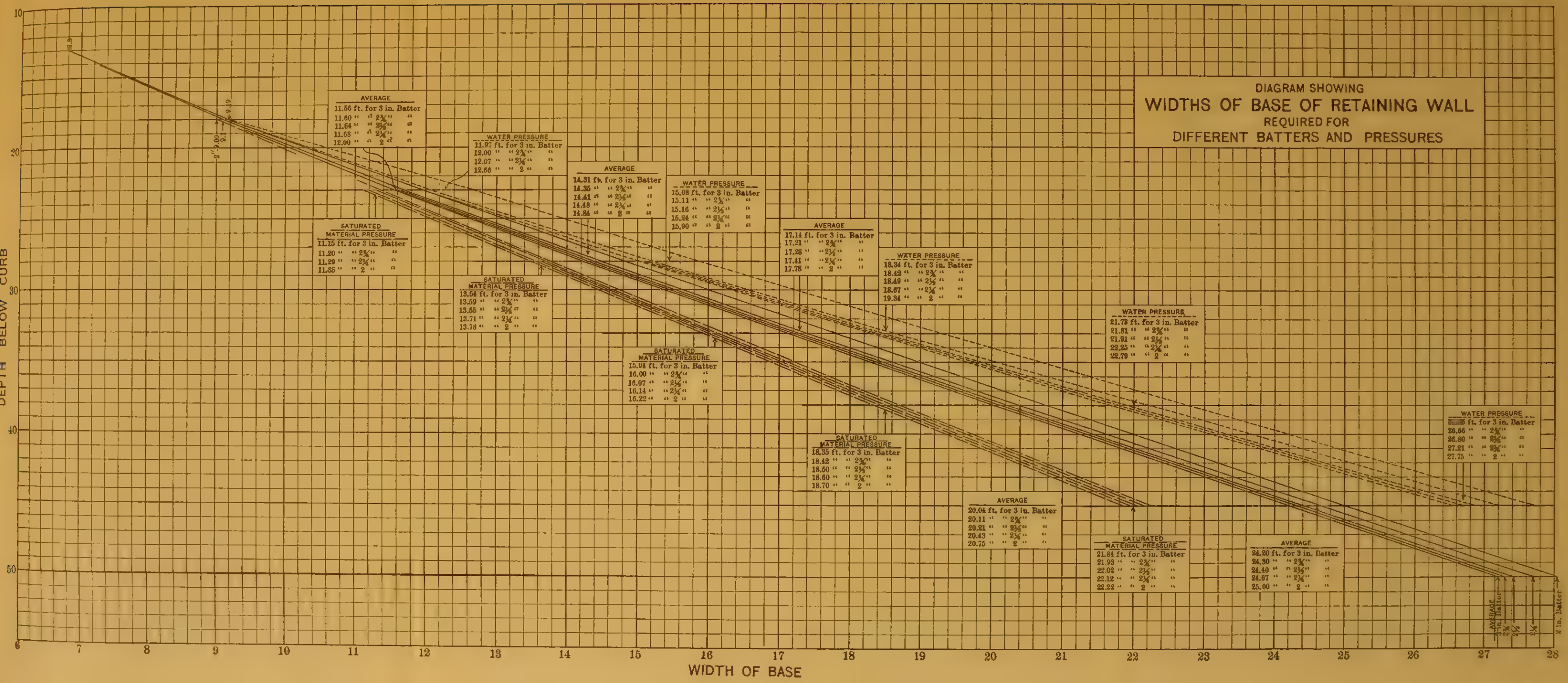


DIAGRAM SHOWING
WIDTHS OF BASE OF RETAINING WALL
REQUIRED FOR
DIFFERENT BATTERS AND PRESSURES
AVERAGE
11.56 ft. for 3 in. Batter
11.60 " " 2¾" "
11.64 " " 2½" "
11.68 " " 2¼" "
12.00 " " 2 " "
WATER PRESSURE
11.97 ft. for 3 in. Batter
12.00 " " 2¾" "
12.07 " " 2¼" "
12.66 " " 2 " "
SATURATED MATERIAL PRESSURE
11.15 ft. for 3 in. Batter
11.20 " " 2¾" "
11.29 " " 2¼" "
11.35 " " 2 " "
AVERAGE
14.31 ft. for 3 in. Batter
14.35 " " 2¾" "
14.41 " " 2½" "
14.48 " " 2¼" "
14.84 " " 2 " "
WATER PRESSURE
15.08 ft. for 3 in. Batter
15.11 " " 2¾" "
15.16 " " 2½" "
15.24 " " 2¼" "
15.90 " " 2 " "
SATURATED MATERIAL PRESSURE
13.54 ft. for 3 in. Batter
13.59 " " 2¾" "
13.65 " " 2½" "
13.71 " " 2¼" "
13.78 " " 2 " "
AVERAGE
17.14 ft. for 3 in. Batter
17.21 " " 2¾" "
17.28 " " 2½" "
17.41 " " 2¼" "
17.78 " " 2 " "
WATER PRESSURE
18.34 ft. for 3 in. Batter
18.42 " " 2¾" "
18.49 " " 2½" "
18.67 " " 2¼" "
19.34 " " 2 " "
SATURATED MATERIAL PRESSURE
15.94 ft. for 3 in. Batter
16.00 " " 2¾" "
16.07 " " 2½" "
16.14 " " 2¼" "
16.22 " " 2 " "
WATER PRESSURE
21.78 ft. for 3 in. Batter
21.81 " " 2¾" "
21.91 " " 2½" "
22.25 " " 2¼" "
22.79 " " 2 " "
SATURATED MATERIAL PRESSURE
18.35 ft. for 3 in. Batter
18.42 " " 2¾" "
18.50 " " 2½" "
18.60 " " 2¼" "
18.70 " " 2 " "
AVERAGE
20.04 ft. for 3 in. Batter
20.11 " " 2¾" "
20.21 " " 2½" "
20.43 " " 2¼" "
20.75 " " 2 " "
WATER PRESSURE
ft. for 3 in. Batter
26.66 " " 2¾" "
26.80 " " 2½" "
27.21 " " 2¼" "
27.75 " " 2 " "
SATURATED MATERIAL PRESSURE
21.84 ft. for 3 in. Batter
21.93 " " 2¾" "
22.02 " " 2½" "
22.12 " " 2¼" "
22.22 " " 2 " "
AVERAGE
24.20 ft. for 3 in. Batter
24.30 " " 2¾" "
24.40 " " 2½" "
24.67 " " 2¼" "
25.00 " " 2 " "
DEPTH BELOW CURB
WIDTH OF BASE
10
20
30
40
50
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28

veloped the fact that the reaction from the superstructure was so great that, for economy, both in first cost and space occupied, the batter must be sufficient to cause that reaction to fall within or very close to the middle third. Nothing could have been gained by having that reaction fall back of the front of the middle third, as the wall was required to be stable against the full pressure before the superstructure was erected, and in case it should ever be removed; or, to state the matter more clearly, the reaction from the superstructure was so great in comparison to the weight of the wall, that, if it fell in front of the resultant of all the other forces, the width of base required would be greatly increased to make the wall stable after the superstructure was erected; whereas, if the reaction from the superstructure fell back of the resultant of all the other forces, the width of base could not be correspondingly decreased without danger of the wall being overturned before the superstructure was erected. The least batter that would answer those conditions was found to be 2 in. per ft.

For convenience in designing, and economy in constructing, the steelwork, the faces of the bridge seat and of the backwall were laid parallel to the center line of the Terminal, and in elevation on line parallel to the top of the curb and as near to it as the economical depth of steel would permit, without bringing the finished construction above the plane fixed in the ordinance. As there is a variation of 13 ft. in the elevation of the top of the curb of 31st Street above the top of the rail and a variation of 18 ft. in 33d Street, a uniform batter, with the top parallel to the center line, would produce a toe varying in distance from it and from the other constructions. It was decided, therefore, for the sake of appearance, to make the face of the wall (or wall produced) at the top of the rail parallel to the center line, and to vary the batter accordingly, using the 2-in. batter previously mentioned as the minimum. This gave a maximum batter of 3 in. per ft. The variation is so gradual that it is unnoticeable, and is not sufficient to introduce any complications in construction.

The wall was designed with a stepped back, primarily to allow the water-proofing and brick protection to be held in position more readily. The first step was put at 13 ft. below the surface of the ground. This gave a vertical back above that point for a 3-in. battered face, and a slightly battered back for sections having a less batter in front. Below that point a step was added for each 5 ft. of depth

to the elevation of the top of the rail, or to the foundation of the wall if above that elevation. As the horizontal distance of the heel of the wall, at its greatest width, from its face at the top of the rail would determine the effective room to be occupied by the wall, it was determined to make the back vertical below the top of the rail and gain the necessary increase in width below that point by making a heavy batter on the face.

The type of wall having been thus determined, calculations were made of the width of base required for each $\frac{1}{4}$-in. batter from 2 to 3 in., inclusive, first for a depth of 13 ft. below the top of the curb and then for each 5 ft. below that elevation, to a depth corresponding to the distance between the top of the curb and the top of the rail at the point of greatest variation. These widths of wall were determined for the two pressures previously decided on, and curves were then plotted showing the thickness of wall required for each batter calculated and for each pressure. They are shown on Plate LXVII. The curves in broken lines represent the widths required for saturated material, and the curves in dotted lines for hydraulic pressure. Mean curves were then drawn between each broken and its corresponding dotted curve. These are shown in solid lines, and represent the widths of wall which were used in the construction. Typical sections of the wall and pipes back of it are shown on Fig. 3.

The extreme positions of the back of the wall on the two streets having been determined, as previously stated, the width of base required at those points fixed the toe of the wall at the top of the rail as 254.5 ft. south of the center line of the Terminal in 31st Street, and 258.5 ft. north of the center line in 33d Street.

Contracts.

The construction was done under the following contracts:

1.—The principal contract, dated June 21st, 1904, was with the New York Contracting and Trucking Company, later assigned by that company to the New York Contracting Company-Pennsylvania Terminal, for the performance of the following works:

- (*a*).—The excavation for and construction of a retaining wall in Seventh Avenue, 31st Street, Ninth Avenue, and 33d Street.
- (*b*).—Excavation over the area enclosed by the retaining wall.
- (*c*).—The building of sewers and the laying of water and gas pipes.

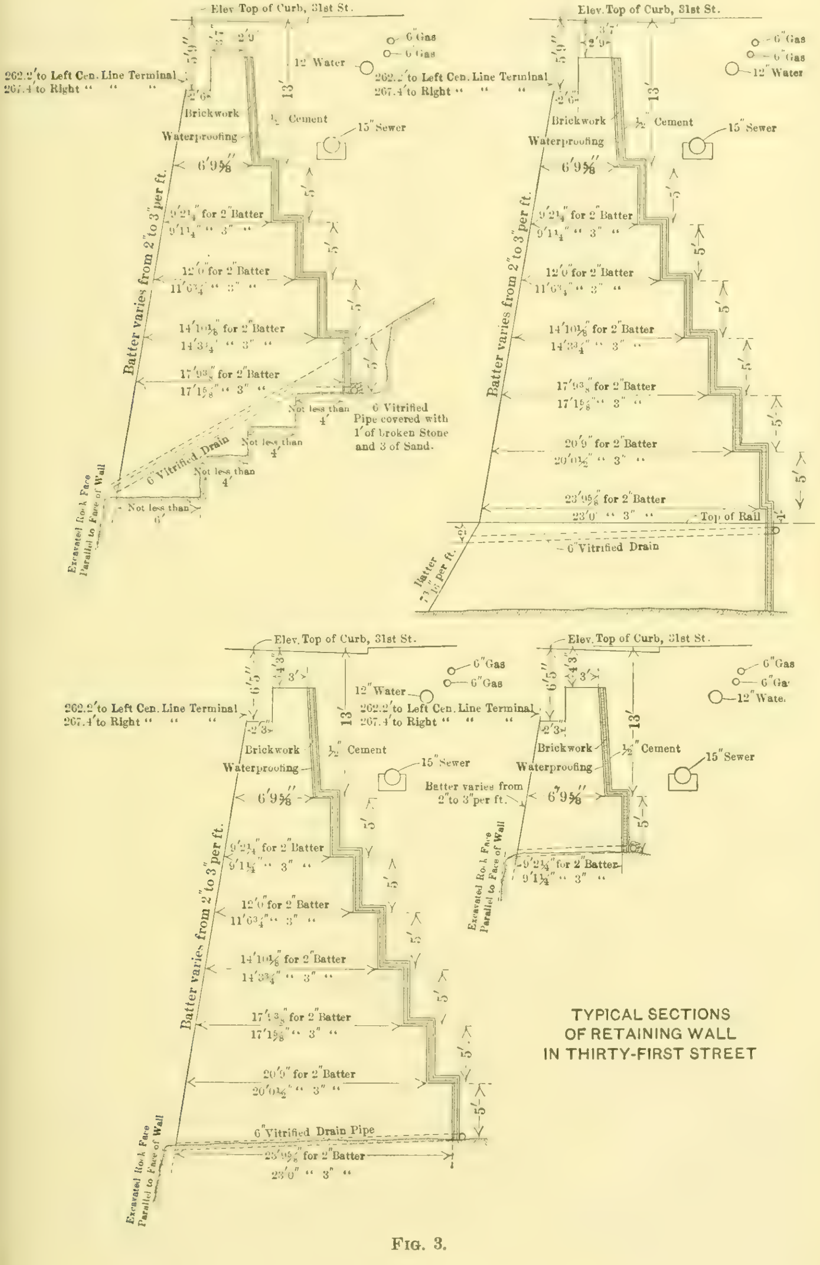

Elev. Top of Curb, 31st St.
262.2′ to Left Cen. Line Terminal
267.4′ to Right " " "
Brickwork
Waterproofing
½″ Cement
15″ Sewer
12″ Water
6″ Gas
6′9⅝″
9′2¼″ for 2″ Batter
9′1¼″ " 3″ "
12′0″ for 2″ Batter
11′6¾″ " 3″ "
14′10⅛″ for 2″ Batter
14′3¾″ " 3″ "
17′9⅜″ for 2″ Batter
17′1⅝″ " 3″ "
20′9″ for 2″ Batter
20′0½″ " 3″ "
23′9⅝″ for 2″ Batter
23′0″ " 3″ "
Batter varies from 2″ to 3″ per ft.
Not less than 4′
Not less than 6′
6″ Vitrified Pipe covered with 1′ of broken Stone and 3′ of Sand.
6″ Vitrified Drain
6″ Vitrified Drain Pipe
Top of Rail
Excavated Rock Face Parallel to Face of Wall
TYPICAL SECTIONS OF RETAINING WALL IN THIRTY-FIRST STREET

FIG. 3.

(*d*).—The building of a timber trestle to support the surface of Eighth Avenue between the south side of 31st Street and the north side of 33d Street, and also the surface of 31st and 33d Streets between Seventh and Ninth Avenues. This refers to the trestles left in place on the completion of the work.

(*e*).—The building of a trestle and bridging from a point near the west side of Tenth Avenue on the south side of 32d Street, westward to the outer end of Pier No. 62, at the foot of 32d Street.

2.—The second contract, dated February 10th, 1905, was with the New York Contracting Company-Pennsylvania Terminal, for the excavation for and construction of retaining walls for the Manhattan Terminal Power Station, and the excavation of the area thus enclosed.

3.—The third contract, dated October 2d, 1907, was with the New York Contracting Company-Pennsylvania Terminal, for the construction of two twin tunnels under Ninth Avenue, and other work incidental thereto.

Sewers and gas mains laid outside the area covered by the foregoing contracts were constructed under the following agreements:

An agreement, dated August 9th, 1904, between the New York Contracting Company-Pennsylvania Terminal, and the New Amsterdam Gas Company, for a 20-in. gas main from Seventh Avenue and 31st Street to 30th Street, and thence to Ninth Avenue, the New Amsterdam Gas Company being remunerated for the cost by the Tunnel Company.

A contract, dated August 24th, 1904, with the New York Contracting Company-Pennsylvania Terminal, for the construction of sewers in Seventh Avenue and in 32d and 33d Streets east of Seventh Avenue.

A contract, dated November 24th, 1908, with the New York Contracting Company-Pennsylvania Terminal, for the construction of a 16-in. gas main from Seventh Avenue and 32d Street to 34th Street, and thence to Eighth Avenue.

All these contracts required that the excavated material be delivered on board scows to be furnished by the company at the pier at the foot of 32d Street, North River. These scows were furnished and the material was disposed of from that point by Henry Steers, Incorporated, under a contract, dated August 9th, 1904, which called for

the transportation to and placing of all material so delivered in the Pennsylvania Railroad Company's freight terminal at Greenville, N. Y.

The disposal of the excavated material was one of the principal features of the work, and, under the above contract, material from those portions of the Terminal site east of Seventh Avenue and west of Ninth Avenue, and from all substructures work, was disposed of, as well as from the constructions herein described. The problem differed from that presented by the usual foundation excavations in New York City in magnitude only, and the methods were not unusual, but were adaptations of the usual ones to exceptionally large work.

Piers and Trestle for Disposal.

The most rapid and economical handling of all excavated material to scows was made possible by the Tunnel Company procuring from the New York Central and Hudson River Railroad Company the pier at the foot of 32d Street, North River, known in the earlier stages of the work as Pier No. 62, but subsequently changed to Pier No. 72, and thus referred to in this paper. This pier was occupied by a freight-shed used by the New York Central Railroad Company, under a long-term lease from the City, and that Company had to make numerous changes in their tracks and adjoining piers before No. 72 could be turned over; the contract for the excavation, therefore, required the contractor to procure any piers needed previous to and in addition to it. Under this clause of the agreement, the contractor procured one-half of the pier at 35th Street, North River, which was used for the disposal of all material excavated previous to May 22d, 1905, on which date Pier No. 72 was first put in service.

As the type of plant the contractor would elect to use could not be determined, previous to the letting of the contract, a general plan for Pier No. 72 and the trestle approach, suitable for either trains or wagons, was attached to the contract, and the details were worked out afterward. The method adopted was by train, and a two-track approach to the pier was provided. Beginning on the east side of Ninth Avenue, at the south line of 32d Street, at an elevation of 20 ft. below the surface, crossing under Ninth Avenue and to the center line of 32d Street, it rose on a 1.5% grade in open cut to the surface of 32d Street at a point 500 ft. west of Tenth Avenue, from which point it rose above the surface of the street on a timber trestle to Tenth Avenue, which

was crossed overhead. West of Tenth Avenue the line changed by a reverse curve to the south sidewalk of 32d Street, and continued on a timber trestle, practically level, to the New York Central Yard tracks near Eleventh Avenue. These tracks and Eleventh Avenue were crossed overhead on a through-truss, steel bridge, and a column-and-girder construction on which the two tracks separated to a distance of 29 ft. between center lines, so as to bring them directly over the posts of special timber bents which spanned the two house tracks of the New York Central south-bound freight shed, which the trestle here paralleled. This position was held to a point 25 ft. west of the east house line of Twelfth Avenue, where, by a system of cross-overs and turn-outs, access was had from either track to six tracks on the pier. Four of these were on upper decks, two on the north and two on the south edge of the pier, at an elevation of 41 ft. above mean high tide, to carry earth and small rock to chutes from which it was dumped into barges. The other two tracks proceeded by a 5.3% grade down the center of the pier to the lower deck where, at a distance of 540 ft. from the bulkhead, and beyond the upper deck construction, they diverged into six, two on the north and two on the south edge of the pier for standing tracks to serve derricks, and two down the center for shifting purposes. A siding to the north of the two running tracks just west of the bottom of the incline served a bank of eight electric telphers. The arrangement of the pier is shown by Fig. 4.

The trestle east of the steel structure at Eleventh Avenue had simple four-post bents, as shown by Bent *"A,"* on Fig. 5, all posts being vertical, to save room at the street level; the outside posts and the caps and sills were of 12 by 12-in. timber; the intermediate posts were of 8 by 12-in. timber; and single or double decks of 3 by 8-in. bracing were used, depending on the height of the bents. These bents were framed on the ground in position and raised by hand. West of Tenth Avenue, the sills of the bents rested on four 12 by 12-in. longitudinal timbers, each spanning two bays and breaking joints, for convenience in supporting the trestle while the tunnels were constructed in open cut beneath. These bents were placed 12 ft. on centers, with one 8 by 16-in. stringer under each rail, and one 6 by 16-in. jack-stringer supporting the overhang of the floor on either side.

The bents along the New York Central freight shed had but two posts of 12 by 14-in. yellow pine varying from 26 ft. to 31 ft. 9 in.

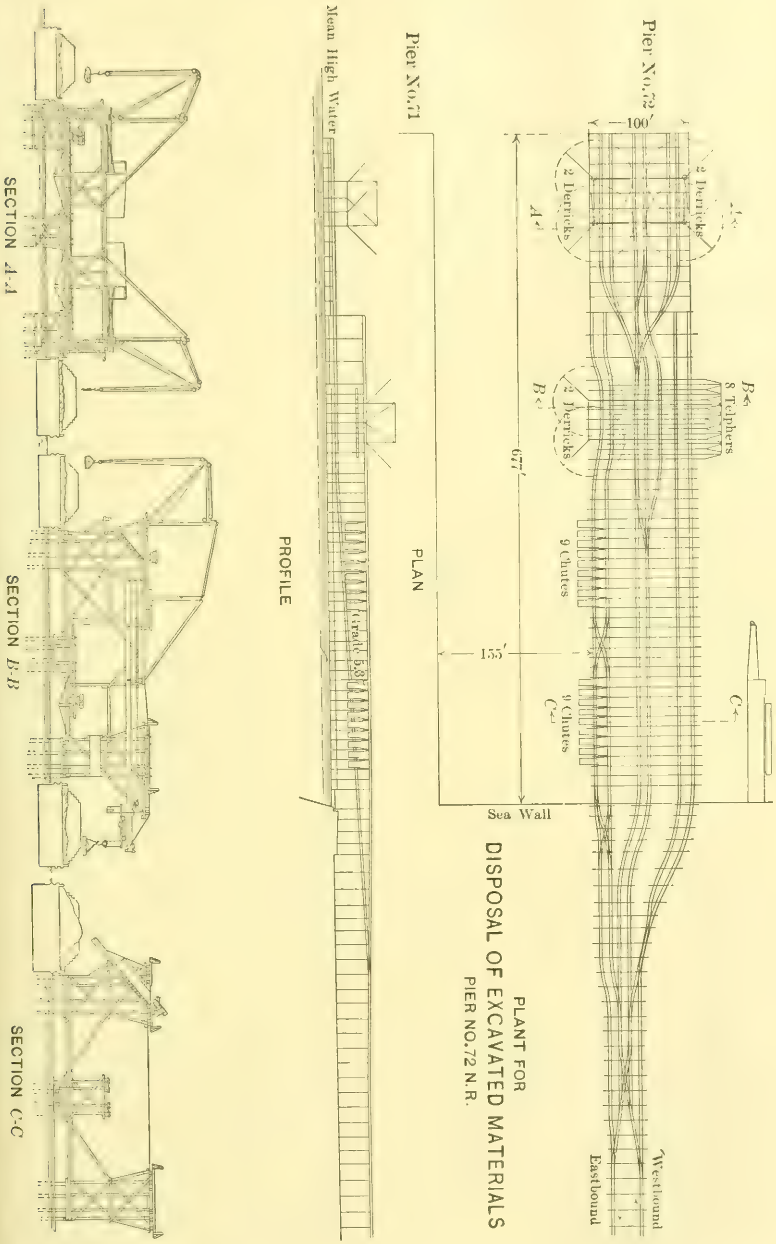

PLANT FOR
DISPOSAL OF EXCAVATED MATERIALS
PIER NO.72 N.R.
Pier No.72
100′
2 Derricks
2 Derricks
A
A
B
8 Telphers
B
2 Derricks
677′
9 Chutes
155′
9 Chutes
C
C
Sea Wall
Westbound
Eastbound
PLAN
Pier No.71
Mean High Water
Grade 5.3
PROFILE
SECTION A-A
SECTION B-B
SECTION C-C

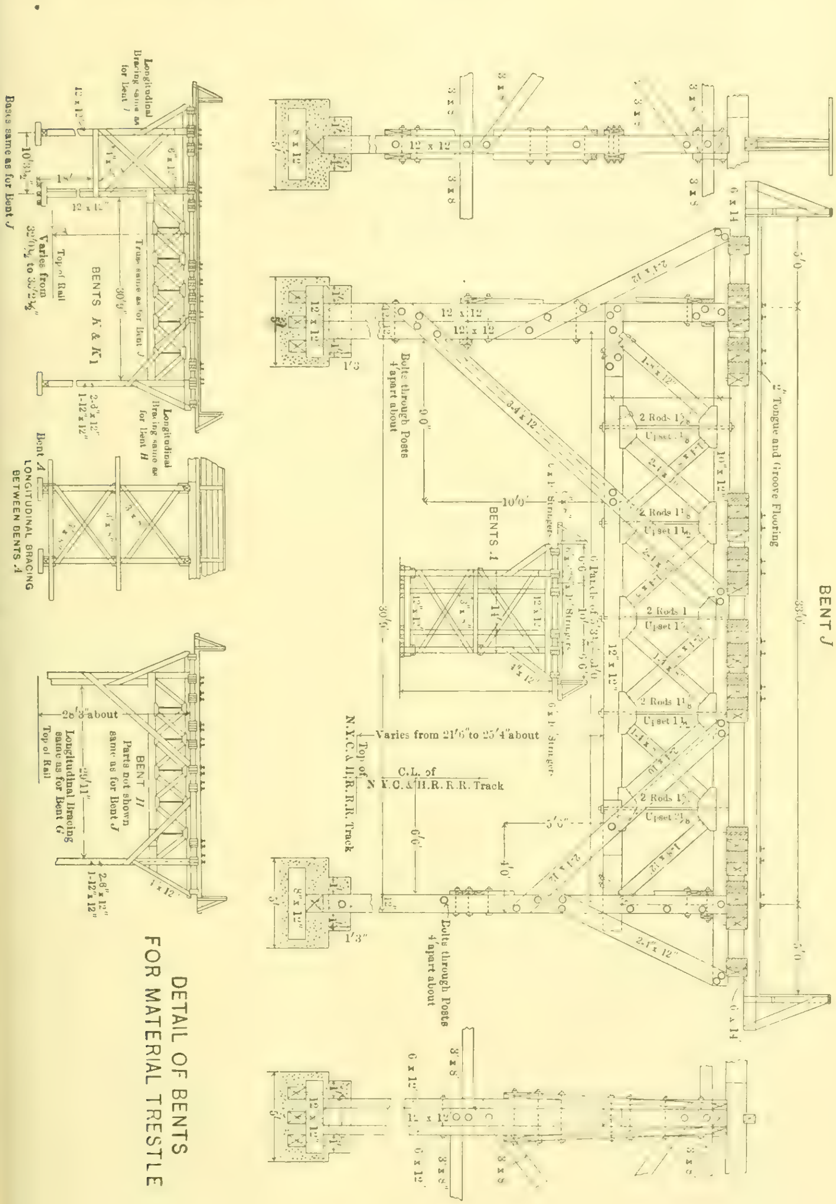
Fig. 4.

from center to center; they had double caps of 12 by 14-in. yellow pine on edge, no bottom sills or bracing, and the vibration and wind pressure were taken care of by the top bracing and anchorage, as shown by Bent *"G,"* on Fig. 6.

The method of erection was as follows: An excavation was made on the line of each post, 4 ft. deep and from 4 to 5 ft. square, depending on whether it was for a single or reinforced post; 6 in. of concrete was placed in the bottom, and on this were laid, at right angles to the center of the trench, three 8 by 12-in. timbers varying in length with the excavation from 3 to 4 ft. To these timbers was drifted one 12 by 12-in. timber of the same length as those in the bottom row, but at right angles to them. Elevations were then taken on top of the 12 by 12-in. timber, and the bent was framed complete and of correct height. The framing was done south of the line of the trestle and west of the freight-house. The framed bents were picked up by a small two-boom traveler carrying two double-drum, electric, hoisting engines, and run forward into position. A hole had previously been made in the metal gutter and canopy of the freight-house, by an experienced roofer, and in the freight platform underneath, and, as soon as the bent had been dropped into position, it was firmly drifted to the foot-blocks, previously described, and the excavation made for them was filled with concrete well rammed about the blocks and rounded off 6 in. above the surface of the ground. Secure flashings, in two sections, were then made about the posts to cover the holes made in the gutter and roof, the bottom sections being firmly soldered to the roof or gutter, and the top sections, which lapped over the bottom and cleared them 2 in. in all directions, were firmly nailed to the posts and the joints leaded. This arrangement allowed the bents to move slightly, and at the same time made the roof and gutter water-tight. These bents were placed 16 ft. on centers to correspond with the spacing of the doors of the freight shed.

Under the cross-overs near Eleventh Avenue, where the tracks had to be supported in different positions on the caps, and could no longer be kept over the posts, the caps were trussed and the posts were reinforced, as shown on Bents *"J," "H"* and *"K,"* Fig. 5.

The trusses for the through bridge over the tracks were erected on Sunday, April 16th. The two trusses, one 122 ft. and the other 165 ft. 8 in. from center to center of end posts, had been assembled



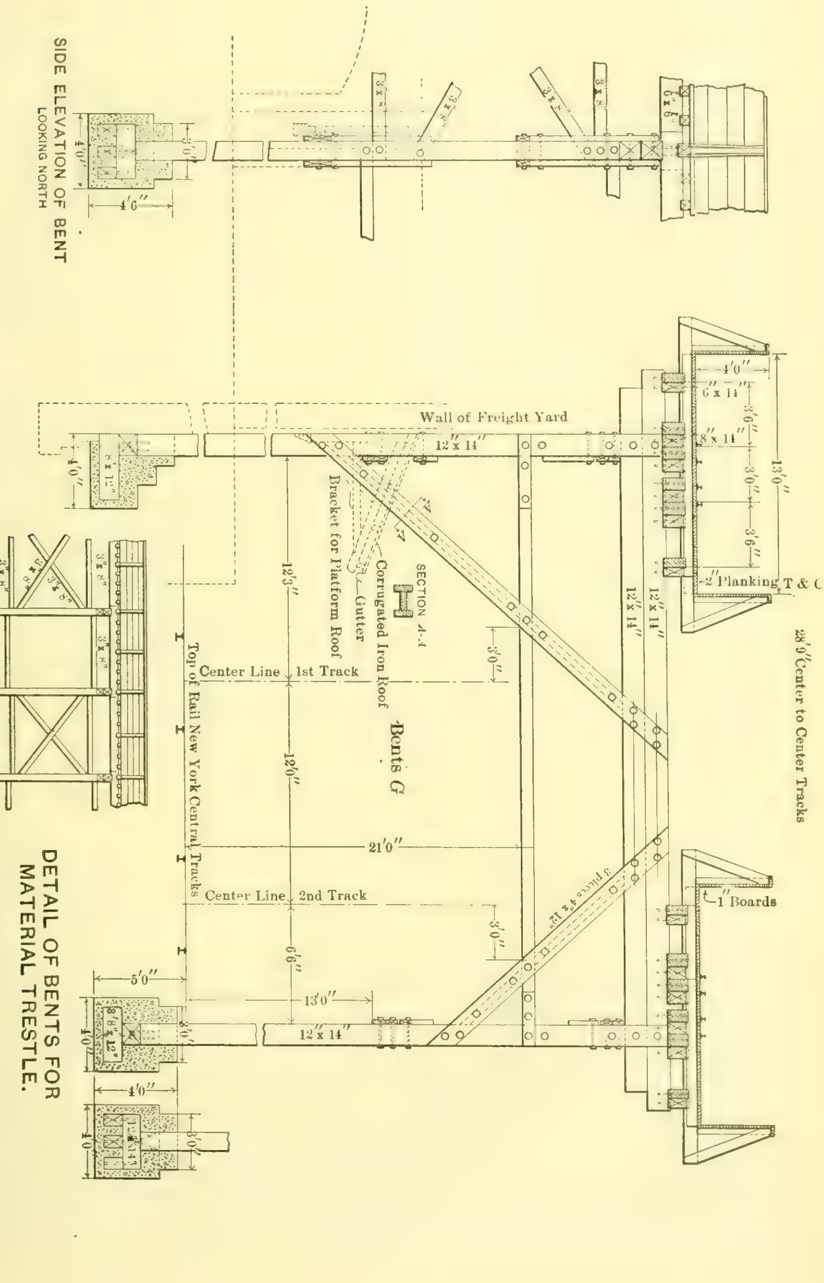
DETAIL OF BENTS FOR MATERIAL TRESTLE

Fig. 5

and riveted, lying flat on cribwork a few feet above the ground, south of the permanent position and between the New York Central tracks and Eleventh Avenue. On the date stated, the contractor, having been given permission to block the Central's tracks from 5 A. M. to 9 P. M., erected a large steel gin pole just south of the correct position of the center of the north truss, which was then dragged, from the place where it had been assembled, across the railroad tracks until the center of the bottom chord was vertically under its true position, the truss still lying flat and about at right angles to the center line of the bridge. Chains were made fast to the top chord at the middle panel of the truss, which was then turned up to a vertical plane, raised to its permanent position, and guyed. The gin pole was then shifted and the operation repeated with the longer truss, after which, half of the floor beams and a part of the top laterals were bolted in position and the guys were removed, the bridge being thus erected without the use of falsework of any kind. During the lifting there was no sag in either truss that could be noticed by the eye. Fig. 1, Plate LXVIII, shows the bridge erected, with the exception of the tight timber fence.

Pier No. 72 is directly over the North River Tunnels. When it was turned over by the New York Central Railroad Company, the contractor for the construction of those tunnels tore down the shed and removed the deck and such piles as were in the path of the tubes. This left standing the four northernmost, the four southernmost and two centers rows of piles for the entire length of the pier. An additional row of piles was then driven on either side of the two center rows, and battered so that at the elevation of the tunnels they would be close to the center rows and leave as much clear space as possible. The pier, therefore, was constructed of three independent lines of four-post bents, which, however, rested on sills which were continuous throughout the width of the pier, as shown by Figs. 2 and 3, Plate LXVIII.

The bents for the upper floors of the pier were double-decked, with 12 by 12-in. posts, sills, intermediate and top caps, and 3 by 8-in. longitudinal and cross-bracing. The bents for the incline were similar, except that those below 16 ft. in height were of single-deck construction. The spacing of the bents varied from 9 ft. 6 in. to 12 ft., except the three outer bays, which had a span of 23 ft., all to agree with the position of the pile bents. The double-deck construction extended for



DETAIL OF BENTS FOR MATERIAL TRESTLE.

Fig. 6.

the full length of the original pier. A single-deck extension, of full width and 180 ft. in length, was subsequently built for the accommodation of four derricks for handling building material and large rock. The piles for this extension were driven in three sets of four rows each, similar to those in the old portion of the pier, except that the bents were driven with a uniform spacing of 15 ft. between centers. The three sets of bents were topped separately with 12 by 12-in. caps and 12 by 12-in. dock stringers; they were braced with both cross and longitudinal low-water bracing, and were tied together by a continuous 12 by 12-in. timber over the dock stringers and 12 by 12-in. packing pieces from stringer to stringer, each of these ties being supported in the center of the span over the tunnels by two 2-in. hog rods, Section "*A-A*," Fig. 4.

The south side of the upper deck of the pier carried three sets of nine hoppers, each set covering 90 ft., a little less than the full length between bulkheads of the largest deck scows, with 70 ft. clear between sets, to allow for the length of a scow outside of the bulkhead and to permit the free movement of boats. Each hopper occupied the full space between two bents, and, as the caps were topped by strips of timber of triangular section, with a width of 12 in. on the base and a height of 6 in., protected by a 6 by 6-in. steel angle, each set of hoppers presented 90 lin. ft. of continuous dumping room. The bottoms of the hoppers, set at an angle of 45°, were formed by 12 by 12-in. timbers laid longitudinally, running continuously throughout each set, and covered by 3-in. planking. The partitions were formed with 4-in. planks securely spiked to uprights from the floor of the hoppers to the caps; these partitions narrowed toward the front and bottom so as to fit inside the chutes. Each hopper was lined on the bottom and sides with ½-in. steel plates, and the bottoms were subsequently armored with 2 by 1-in. square bars laid 3 in. on centers and bolted through the 12 by 12-in. flooring of the hoppers. The chutes, extending from the bottom of the hoppers, were 20 ft. long and 7 ft. wide, in the clear; they were formed entirely of steel plates, channels, and angles, and were supported from the upper deck of the pier by chains; their lower ends were 17 ft. above mean high tide and 14 ft. 6 in. from the string piece of the pier. The hoppers and chutes are shown by Fig. 1, Plate LXIX.

A length of 150 ft. of the north side of the pier was for the use of the contractor for the North River tunnels; it was equipped with a set

FIG. 1.—MATERIAL TRESTLE OVER N. Y. C. & H. R. R. R. CO.'S TRACKS.

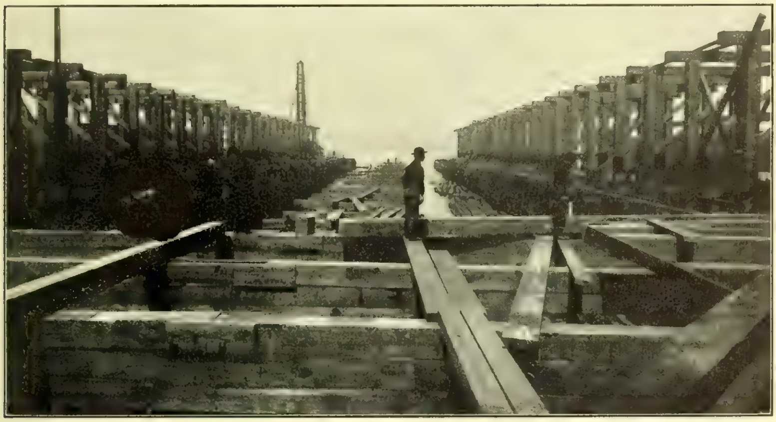


FIG. 2.—MATERIAL TRESTLE UNDER CONSTRUCTION ON PIER NO. 72, NORTH RIVER, SHOWING CLEAR WATER OVER TUNNEL LOCATION.

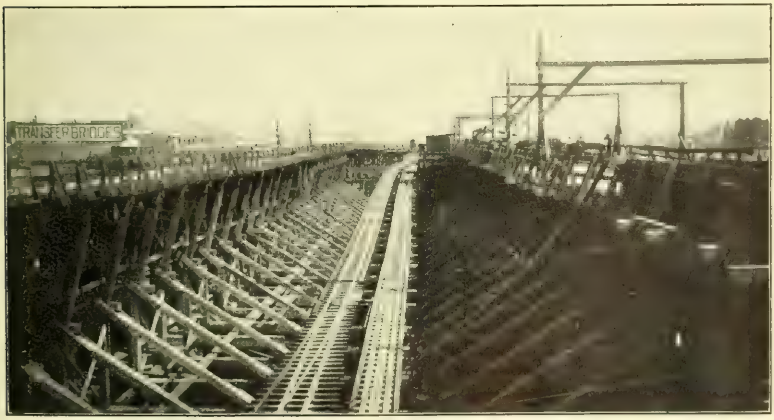


FIG. 3.—PIER NO. 72, NORTH RIVER, SHOWING INCLINE AS RECONSTRUCTED FOR LOCOMOTIVES.

of nine chutes similar to those for the south side; they were used but little, and were finally removed to make room for a cableway for unloading sand and crushed stone.

At the foot of the incline there was a bank of eight telphers running on rails securely bolted to the tops of 20-in. I-beams, which were hung from stringers resting on the upper caps. The beams were erected in pairs, each pair being securely braced together and to the trestle posts to prevent swaying. Each telpher occupied the space between two bents, about 10 ft., so that the entire bank commanded a length of 80 ft., which was approximately the length of a rock scow between bulkheads. All supports for the telphers were provided as a part of the trestle, but the machines themselves were a part of the contractor's plant.

Four derricks were erected on the extension, two on the north and two on the south edge of the pier, supported on bents at a sufficient elevation above the floor to clear a locomotive.

After most of the earth had been excavated, the out-bound set of hoppers on the south side of the pier was removed, and two derricks were erected in their place and used for unloading sand, crushed stone, and other building material.

Plant.

As the use of the 35th Street pier for the disposal of material required that the mode of transportation should be by dump-wagons drawn by horses, the plant in use by the contractor during that period necessarily differed in many respects from what it was later, when Pier No. 72 was available. Therefore, the nature of the plant during each period will be stated. The plant for each period will be divided into five classes:

1.—Central Plant:
   (*a*) Power-Generating Plant.
   (*b*) Repair Shops.
2.—Retaining-Wall Plant.
3.—Pit-Excavating Plant.
4.—Transportation Plant.
5.—Dock Plant.

Horse-and-Truck Period: July 11th, 1904, to May 22d, 1905.

1.—Central Plant.

(*a*).—*Power-Generating Plant.*—The contractor's first central generating plant was established in a 35 by 85-ft. steel-framed building covered with corrugated iron, the long side being parallel to Ninth Avenue and 15 ft. from the east house line, and the north end 43 ft. south of the south house line of 32d Street. The foundations for the building and machinery were of concrete, resting on bed-rock, the floor being 20 ft. below the level of the Ninth Avenue curb. The south end of the building was the boiler-room and the north end the compressor-room, the two being separated by a partition. Coal was delivered into a large bin, between the boiler-house and Ninth Avenue, its top being level with the street surface, and its base level with the boiler-room floor.

At the end of the horse-and-truck period the plant consisted of:

Two Rand, straight-line compressors, 24 by 30 in., having a capacity of 1 400 cu. ft. of free air per min. when operating at 86 rev. per min. and compressing to 80 lb. above atmospheric pressure.

One 10 by 6 by 10-in., Worthington, steam, plunger pump.

Three horizontal boilers of the locomotive type, each of 125 h.p.

(*b*).—*Repair Shops.*—The repair shops, which included blacksmith, machine and carpenter shops, were located on the first floor of a 40 by 70-ft. two-story frame structure, located in the pit on the north side of 31st Street 48 ft. east of Ninth Avenue. The second floor was on the street level, and was used as a storehouse for hand-tools and small plant.

The blacksmith shop contained: Four forges with hand blowers, four anvils, and hand-tools.

The machine shop contained: One drill press, one shaper (14-in. stroke), one 18-in. swing lathe, and one 6-in. bed lathe.

The carpenter shop contained: One circular saw, one wood lathe, and hand-tools.

The plant in both machine and carpenter shops was operated by one 7½-h.p. General Electric motor, the current for which was obtained from the Edison Electric Heat, Light, and Power Company.

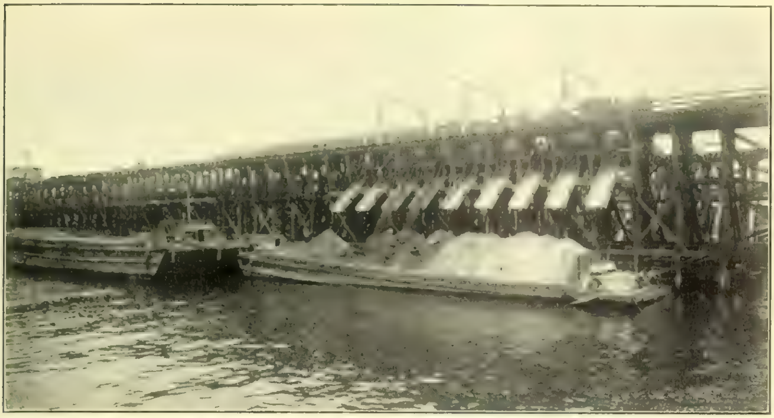


FIG. 1.—MATERIAL TRESTLE, SHOWING FIRST CHUTES IN OPERATION.

FIG. 2. EAST PIT. STEAM SHOVEL LOADING EXCAVATED MATERIAL ON CAR.

FIG. 3.—WEST PIT, SHOWING CONDITION ON JUNE 28TH, 1905.

2.—Retaining-Wall Plant.

Three cableways, with 35-ft. towers of 12 by 12-in. yellow pine timber capable of spanning 350 ft., and operated by 7 by 10-in. double-drum Lambert hoisting engines mounted with 25-h.p Lambert upright boilers.

Five stiff-leg derricks, with masts from 35 to 50 ft. long and booms from 45 to 60 ft. long, operated by 7 by 10-in. Lambert double-drum and swinging gear engines, mounted with 25-h.p. upright Lambert boilers.

Six Cameron pumps, varying in size from 7 by 6 by 13 in. to 10 by 8 by 16 in. The first dimension referring to the diameter of the steam cylinder, the second to that of the water, and the third to the stroke.

Five Rand sheeting drivers.

Two Ransome ⅝-cu. yd. concrete mixers, mounted on frame, with kerosene driving engine.

Drills drawn from pit plant as required.

3.—Pit-Excavating Plant.

One guy derrick, 50-ft. mast and 45-ft. boom, operated by a Lambert two-drum and swing-gear hoisting engine, with Lambert 25-h.p. upright boiler.

Three stiff-leg derricks, similar to those used on the retaining wall work.

Three Bucyrus, 70-ton steam shovels with 3½-cu. yd. dippers.

One traveling derrick, built with an A-frame of 12 by 12-in. timbers, 15-ft. mast, and 25-ft. boom; the traveler carried an engine and boiler similar to those used on the stiff-leg derricks, and was used on the Seventh and Eighth Avenue sewers, as well as in the pit.

Ten Rand-Ingersoll rock drills, Nos. 1, 3¼, and 4.

One Reliance stone crusher (nominal capacity 17 tons of crushed stone per hour) belt-driven by 50-h.p. engine.

4.—Transportation Plant.

During the whole of the first period the transportation plant consisted of two-horse trucks and snatch teams as needed. The number varied greatly from 25 at the beginning and end of

the period to an average of 135 from August 1st to December 1st, 1904, about 10% of the total number of teams being used as snatch teams.

5.—Dock Plant.

The only machinery used on the dock during the horse-and-truck period was one stiff-leg derrick similar in size and operation to those described under the head of retaining-wall plant.

The plant described above does not represent that which was used during the whole of the horse-and-truck period, but what had accumulated at the end of it. The power-generating plant might almost have been omitted from this period, as the first compressor did not begin running until February, 1905. Previous to that time, the power for drilling, pumping, driving, sheeting, etc., was steam furnished by the boilers which subsequently drove the compressors, these being brought on the ground and fired as occasion required.

Train-Disposal Period, Beginning May 22d, 1905.

At the beginning of this period there had been excavated 242 800 cu. yd. of earth and 22 800 cu. yd. of rock, of the total excavation of 803 500 cu. yd. of earth and 804 000 cu. yd. of rock included in the principal contract, leaving to be excavated under that contract 560 000 cu. yd. of earth and 781 200 cu. yd. of rock, and an additional contract had been let to the New York Contracting Company for the terminal power station, which increased the earth by 16 500 and the rock by 15 500 cu. yd. During the year following, contracts for the east and west portions and the sub-structures were let, which brought the total to be excavated, after the beginning of the train-disposal period, up to 681 000 cu. yd. of earth and 1 494 000 cu. yd of rock.

The central plant, transportation plant, and dock plant were used indiscriminately on all these contracts, and, as no separation can be made which will hold good for any appreciable length of time, the plant in those classes will be stated in total. The retaining-wall and pit plant here given include that used on the principal contract and terminal power station only. The power-generating plant given under the horse-and-truck period was doubled at the beginning of the train-disposal period, but it was still insufficient for the work then under contract, and the additional contracts necessitated a greater increase. The location had also to be changed to permit the excavation of the rock under Ninth Avenue. The old stone church fronting on 34th

Street between Seventh and Eighth Avenues, a building 68 ft. wide and 92 ft. long, made a roomy and very acceptable compressor-house. The wooden floors and galleries were removed, and good concrete foundations were put in, on which to set the plant; the walls, which were cracked in several places, were trussed apart and prevented from moving outward by cables passed about the pilasters between the windows.

The boilers were erected south of the church, an ash-pit being first built, the full width of it, with the floor on a level with the basement. The rear wall of the church formed the north wall of the ash-pit, and the south wall and the ends were built of concrete. The boilers were set with the fire-doors toward the rear wall of the building, and 7 ft. distant from it, and above this fire-room and the boilers there was erected a coal-bin of 500 tons capacity. The rear wall of the compressor-house formed the north wall of the bin, the section of which was an isosceles right-angled triangle. Coal was delivered by dumping wagons into a large vault constructed under the sidewalk on 34th Street, and was taken from there to the bin by a belt conveyor.

The plant for the second period was as follows:

1.—Central Plant.

(*a*).—*Power-Generating Plant.*—The plant in the engine-room consisted of:

Three Rand straight-line compressors from the original power plant at Ninth Avenue and 32d Street.

One Ingersoll straight-line compressor from the old power-house.

One Rand duplex Corliss, 40 by 48-in. air compressor, with both air and steam cylinders cross-compounded, and a capacity of 5 600 cu. ft. of free air per min. compressed to 80 lb. at 70 rev. per min.

Three Rand duplex, 30 by 30-in., compressors, connected with 525-h.p., 6 600-volt, General Electric motors, with a capacity of 3 000 cu. ft. of free air per min. compressed to 80 lb. at 125 rev. per min.

Two 10 by 6 by 10-in. Worthington steam plunger pumps.

One 7½-h.p. General Electric motor for driving the Robbins belt coal conveyor.

One forced-draft fan (built by the Buffalo Forge and Blower Company), driven by an 8 by 10-in. Buffalo engine.

In the boiler-room there were three 500-h.p. Sterling water-tube boilers.

(*b*).—*Repair Shops.*—The repair shops remained in their old location until sufficient room had been excavated to sub-grade in the lot east of Eighth Avenue, and then they were moved to the old Ninth Avenue power-house which had been erected at that point. The contents of the blacksmith shop remained the same as for the first period. The equipment of the machine shop was increased by one 18-ton trip-hammer operated by air and one bolt-cutting machine, size ¼ in. to 1½ in. The carpenter shop remained the same except that the electric motor was replaced by a 25-h.p. single-cylinder air motor; there was added to the repair shop a drill shop containing: Four forges with compressed air blowers, four anvils, two Ajax 20-ft. drill sharpeners, and one oil blower forge.

2.—Retaining-Wall Plant.

The retaining-wall plant was identical with that described for the first period, with the addition of two Ransome 1-cu. yd., concrete mixers, with vertical engines mounted on the same frame, using compressed air.

3.—Pit-Excavating Plant.

The pit-excavating plant included that listed for the first period and, in addition, the following:

- One Vulcan, 30-ton, steam shovel, with 1-cu. yd. dipper and a vertical boiler.
- One Ohio, 30-ton, steam shovel, with 1-cu. yd. dipper and a vertical boiler.
- Four guy derricks (50 to 80-ft. masts and 45 to 60-ft. booms), operated by Lambert 7 by 10-in. engines, with two drums and swinging gear, mounted with 25-h.p. vertical boilers, but driven by compressed air.
- Seventy Ingersoll-Rand rock drills, Nos. 1, 3¼, and 4.
- Two Rand quarry bars, cutting 10 ft. in length at one set-up, and mounted with No. 4 drill using a **Z**-bit.

4.—Transportation Plant.

- Twenty-one H. K. Porter locomotives, 10 by 16-in., and 36-in. gauge.
- Three Davenport locomotives, 9 by 16-in., and 36-in. gauge.

One hundred and forty Western dump-cars, each of 4 cu. yd. capacity.

One hundred and sixty-five flat cars, with iron skips, each of 4 cu. yd. capacity.

5.—Dock Plant.

Four stiff-leg derricks on extension, having 35-ft. masts and 40-ft. booms, and each operated by a 60-h.p. Lambert, three-drum, electric, hoisting engine.

One stiff-leg derrick, on the south side of the pier on the upper deck, with a 28-ft. mast operated by a three-drum Lambert engine and a 25-h.p. vertical boiler.

One stiff-leg derrick, on the north side of the dock on the upper deck, used exclusively for bringing in brick, electric conduit, pipe, and other building material, operated when first erected by a three-drum, steam-driven, Lambert, hoisting engine. This engine was later changed to the derrick on the south side of the dock, and a motor-driven Lambert engine from that derrick was substituted.

Eight electric telphers.

Ninth Avenue Twin-Tunnels Plant.

One stiff-leg derrick, previously used in retaining-wall work.

One Smith concrete mixer, 1 cu. yd. capacity, driven by attached air engine.

Two cableways taken from the retaining-wall plant and used for mucking out the tunnels after the center pier had been built; driven by air supplied to the original engine.

One Robbins belt conveyor, driven by a 30-h.p. engine run by air.

Three 1-cu. yd. Hopple dump-cars.

Construction.

Ground was broken for work under the principal contract on July 9th, 1904, on which date the contractor began cutting asphalt for Trench No. 1 in 31st Street, and also began making a roadway from Ninth Avenue into the pit just south of 32d Street.

Excavation for Retaining Walls.—Two essentially different methods were used in excavating for and building the retaining walls; one, construction in the trench, the other, construction on the bench. In general, the trench method was used wherever the rock on which

the wall was to be founded was 12 ft. or more below the surface of the street; or, what is perhaps a more exact statement, as it includes the determining factor, where the buildings adjoining the wall location were not founded on rock.

In the trench method the base of the wall was staked out on the surface of the ground, the required width being determined by the elevation of the rock, as shown by the borings. The contractor then added as much width as he desired for sheeting and working space, and excavated to a depth of about 5 ft. before setting any timber. In some cases the depth of 5 ft. was excavated before the cableway or derrick for the excavation was erected, the wagons being driven directly into the excavation and loaded by hand, but, usually, the cableway was first erected, and buckets were used from the start. After the first 5 ft. had been excavated, two sets of rangers and struts were set, the first in the bottom of the excavation and the second at the level of the street surface, supported by posts resting on the bottom rangers. The sheeting was then set, and all voids back of it were filled with clean earth and well tamped. The toe of the sheeting was kept level with the bottom of the excavation until the ground-water was reached, after which it was kept from 3 to 5 ft. ahead of the digging.

The sheeting used was 3-in., in variable widths; it was always tongued and grooved on the side of the trench next to the buildings and in the deeper excavations on both sides of the trench, and was driven by wooden mauls above the ground-water level, but steam sheeting-drivers were used below that elevation. Struts, rangers, and posts were generally 12 by 12-in.

Some exceedingly bad material was encountered in the deeper excavations, beds of quicksand being passed through, varying in thickness from 1 to 18 ft., the latter, in 31st Street between Seventh and Eighth Avenues, in the deepest excavation made. After encountering the fine sand in that trench, no headway was made until a tight wooden cylinder was sunk through the sand by excavating the material inside of it and heavily weighting the shell with pig iron. When this cylinder had reached the gravel, which lay below the sand, it was used as a sump, and the water level was kept below the bottom of the excavation, which permitted good progress. Sand continued to flow under the sheeting to such an extent, however, that the front walls of

four adjoining buildings were badly cracked and had to be taken down and rebuilt. All the stoops along this trench settled, and had to be repaired.

The bench method of excavating for the retaining wall was very simple, and was used only where the rock lay near the surface and the adjoining buildings were founded on it, the overlying material being in such case dry, and consequently firm, little or no shoring was required. The method was to extend the pit excavation to a width of 2 or 3 ft. beyond the proposed back of the retaining wall, and to carry that width down to the depth required for its base, below which the excavation was narrowed to 1 ft. inside of the face of the wall and continued either before it was built or subsequently.

Retaining-Wall Construction.—The concrete walls were built in sections 50 ft. in length, except where that spacing would bring an expansion joint under a girder pocket or just on line with a tier of struts, in which cases the section was shortened as required. Trenches were never allowed to remain open at the full depth, the concreting being started as soon after the necessary length of rock had been uncovered as the forms and preliminary work for a section could be prepared. Each section was a monolith, except in a few cases where very heavy rains made it impossible to hold the laborers.

The various operations in building the concrete wall are shown on Fig 7. Guide-planks, "*a a*," Section "*A-A*," were securely spiked to alternate tiers of struts for the length of the section, the face of each guide-plank being set on line with the intended face of the concrete wall, and 2-in. tongued-and-grooved spruce plank were laid along the guide-plank to the height of the bottom strut and securely braced from the front sheeting. A 4-in. brick wall was built simultaneously on line with the back of the wall to the height of the first step. Where the bottom strut was below that elevation, the brickwork was left low at that immediate point and built up when the strut was removed. The brick wall was then water-proofed on the side toward the concrete, and loose laps of the water-proofing were allowed to hang over the brickwork and at least 8 in. down the back. A 6-in. vitrified pipe drain was then laid along the surface of the rock just outside of the brick wall, the joints in the pipe being caulked with oakum saturated in cement, and pointed with cement mortar above a line 1 in. below the horizontal diameter, the remainder of each joint being left open. Cross-drains

were laid from tees in the back drain to the face of the wall at all low points in the rock and at least for every 25 ft. of wall length, the joints of these discharge pipes being caulked and cemented throughout. The surface of the rock was then washed and scraped clean, and was covered with about 1 in. of mortar, after which the section was ready for concrete.

The building of monolithic sections in trenches required that the thrust from one set of struts be taken by the concrete before the set above could be removed, and necessarily caused slow progress, the rate at which concrete was deposited being just sufficient to prevent one layer from setting before the next layer above could be placed.

The concrete used was mixed in the proportions of 1 part of cement to 3 parts of sand and 5 parts of stone, in 2-bag batches, in $\frac{3}{4}$-yd. and 1-yd. Ransome portable mixers mounted with air-driven engines on the same frame. These mixers were placed at the surface, and were charged with barrows, the correct quantities of sand and stone for each batch being measured in rectangular boxes previous to loading the barrows. The concrete was discharged from the mixer into a hopper which divided into two chutes, only one of which was used at a time, the concrete being shoveled from the bottom of the chutes to its final position. Facing mortar, 2 in. thick, was deposited simultaneously with the concrete, and was kept separate from it by a steel diaphragm until both were in place, when the diaphragm was removed and the two were spaded together. The bottoms of the guide-planks were cut off just above the concrete as it progressed, and, as soon as the wall had reached a strut at one end of the section, that strut was removed, the form was built up to the next strut, at front and back, and braced to the sheeting, so that, by the time the entire length of the section had been carried up to the level of the first line of struts, forms were ready at one end for the succeeding layers. The layers of concrete never exceeded 8 in. in height, and at times there were slight delays in the concreting while the carpenters made ready the next lift of forms, but such delays were rarely long enough to permit the concrete to take its initial set.

After a section of concrete had firmly set, both back and front forms were removed, and the thrust from the sides of the trench was transferred directly to the finished wall. The face of the wall was rubbed with a cement brick to remove the marks of the plank, and

SKETCH SHOWING FORMS FOR, AND METHOD OF, CONCRETING RETAINING WALLS IN TRENCH.

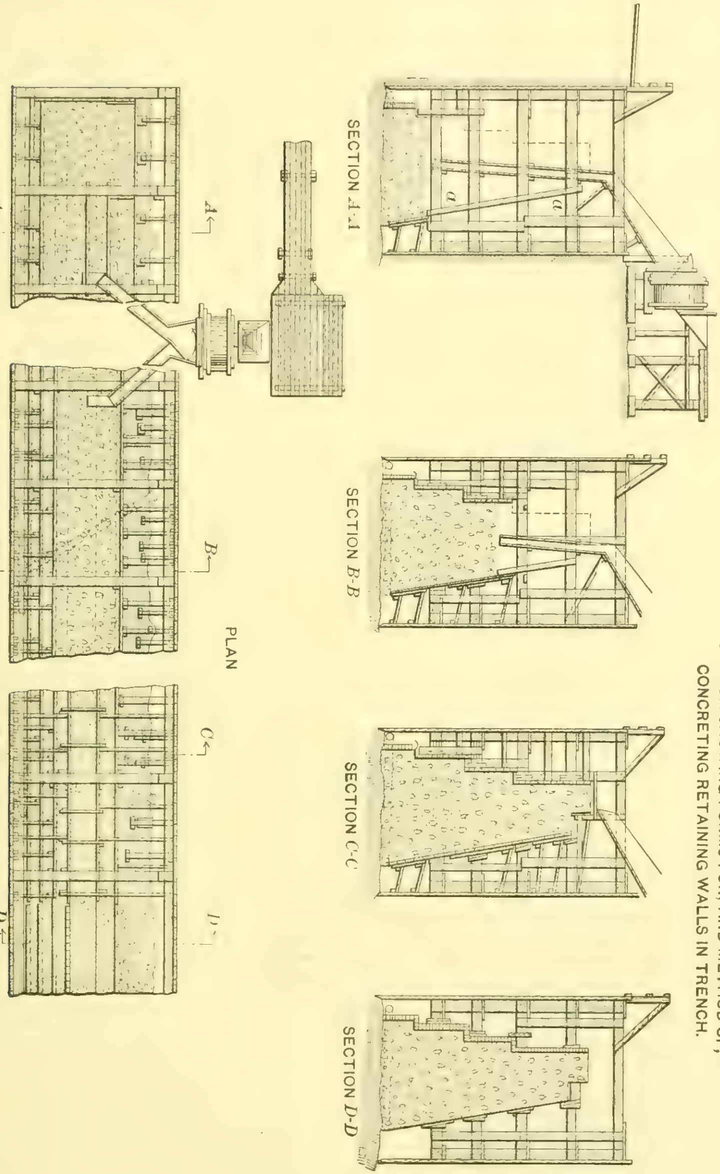


Fig. 7.

was then coated with a wash of thin cement grout. The water-proofing and brick armor were then continued up the back of the wall, the spaces between the lines of braces being first water-proofed and bricked, and the braces transferred to the finished surface, after which the omitted panels were completed. The water-proofing consisted of three layers of Hydrex felt, of a brand known as Pennsylvania Special, and four layers of coal-tar pitch. The pitch contained not less than 25% of carbon, softened at 60° Fahr., and melted at a point between 96° and 106° Fahr. The melting point was determined by placing 1 gramme of pitch on a lead disk over a hole, $\frac{5}{16}$ in. in diameter, and immersed in water which was heated at the rate of 1° per min.; the temperature of the water at the time the pitch ran through the hole was considered as the melting point.

In order to prevent the water-proofing from being torn at the joint between sections when they contract from changes in temperature, a vertical strip of felt, 6 in. wide, was pitched over each joint, lapping 3 in. on each concrete section. The back of this strip was not pitched, but was covered with pulverized soapstone, so that the water-proofing sheet was free from the wall for a distance of 3 in. on either side of each joint.

Concreting was continued during the severest weather, one section being placed when the thermometer was 5° above zero. When the thermometer was below the freezing point both sand and stone were heated by wood fires in large pipes under the supply piles; the temperature of the mix was taken frequently, and was kept above 40 degrees. Numerous tests made while the work was in progress showed that, while the temperature fell slightly soon after the concrete was deposited, it was always from 2° to 5° higher at the end of 2 hours. The face and back of the concrete were prevented from freezing by a liberal packing of salt hay just outside the forms.

A vertical hog trough, 24 in. wide and 9 in. deep, was placed in one end of each section, for its full height below the bridge seat, into which the next section keyed, and, when the temperature at the time of concreting was below 50° Fahr., a compression joint was formed by placing a strip of heavy deadening felt, 2 ft. wide, on the end of the completed section next to the face and covering the remainder of the end with two ply of the felt and pitch water-proofing; the one ply of deadening felt near the face was about the same thickness as the

two ply of water-proofing, and was used to prevent the pitch from being squeezed out of the joint to the face of the wall.

The excavation for the retaining walls in 31st and 33d Streets were in all cases made of sufficient width to receive the sewers, which were laid as soon as the back-fill, carefully rammed and puddled, had reached the proper elevations; the back-filling was then completed, and the gas and water mains were afterward laid in separate trenches.

The sections of concrete built in trench varied in height from 13 to 59 ft. from the base to the top of the back wall. With the exception of the Seventh Avenue wall, 50 ft. in height, and the Ninth Ave-

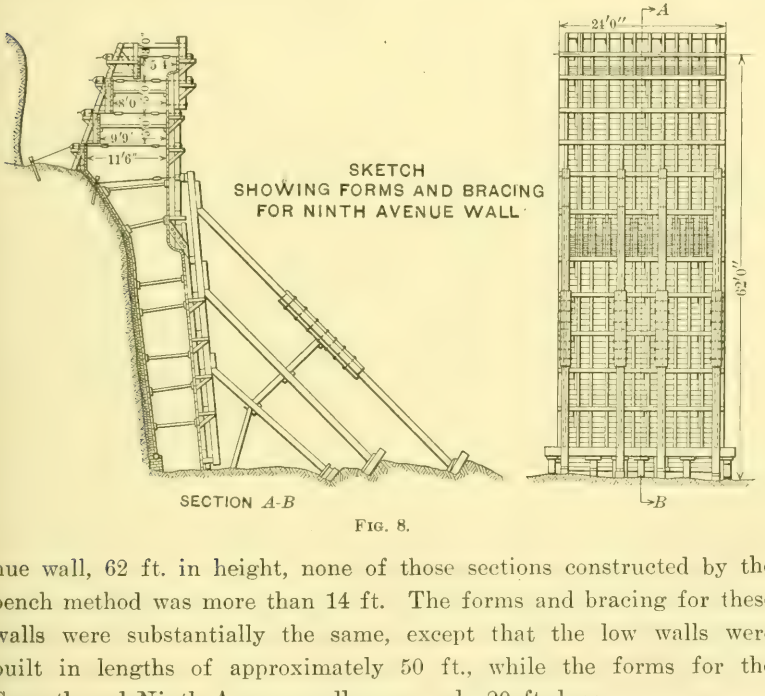


FIG. 8.

nue wall, 62 ft. in height, none of those sections constructed by the bench method was more than 14 ft. The forms and bracing for these walls were substantially the same, except that the low walls were built in lengths of approximately 50 ft., while the forms for the Seventh and Ninth Avenue walls were only 20 ft. long.

The forms and bracing for the Ninth Avenue walls are shown on Fig. 8. These forms were built in one piece and moved ahead from section to section, and they were firmly braced from the bottom with raker braces to a point 36 ft. above the base, the upper part being held in place by $\frac{3}{4}$-in. bolts passed through the forms and anchored by cables to bolts grouted into the rock behind.

After the forms had been set and braced, an 8-in. brick wall was laid up the face of the rock, containing a vertical line of three-cell hollow tile block every 5 ft. of length, and laid to conform as nearly as possible to the face of the rock, all voids being filled with broken stone. Water-proofing, similar to that described for the walls in the trench, was then applied to the brick and tile wall for the full height, and firmly braced to the front forms, the braces being removed as the concrete reached them. The concrete was mixed at the street level and deposited through chutes, as described previously.

Tables 1, 2, and 3 show the quantity of cement used in each section of retaining wall, and give figures by which the quantities of other materials may be determined.

Pit Excavation.—The pit excavation during the horse-and-truck period was largely preparatory work done to get the excavation in good shape for handling spoil trains after Pier No. 72 and the trestle approach were finished. This required an open cut from Ninth to Seventh Avenues at a sufficient depth below the sewers and other substructures in the avenues to clear a locomotive, and wide enough for both running and loading tracks, also the building of the cast-iron sewer in Eighth Avenue across the entire excavation, with enough of the temporary bridging to support it. The building of the trestle in Eighth Avenue was essentially a part of the pit excavation, as the progress of one depended greatly on that of the other.

Excavation was commenced on July 12th, 1904, for the crossing under Ninth Avenue, and in the pit east of Ninth Avenue along 32d Street. The line chosen for the opening cut was down the center of the pit, as it was not safe to excavate near the bounding streets until after the completion of the enclosing retaining wall. The excavation was started by hand, but three 70-ton Bucyrus steam shovels were put to work as soon as they could be delivered, the first on July 25th and the third on September 12th. The excavated material was loaded by the shovels on end-dump wagons, each having a capacity of 2 cu. yd., and was conveyed in them to the dumping board at 35th Street. The average number of teams was 140, 10% being snatch teams to pull the wagons out of the pit and to assist them up the runway at the dumping board. The teams averaged only seven trips per day of 10 hours, considerable delay being caused by the trains of the New York Central Railroad at Eleventh Avenue. The number of teams

was not sufficient, therefore, to keep the three shovels busy when they were all in good digging, but the dumping board was taxed to accommodate that number, and little would have been gained by increasing it. The digging was very good during this period, practically no rock being encountered, and the building foundations were too light to present any obstacle to such powerful shovels. The capacity of their dippers was 3½ cu. yd., so that one dipperful meant one truck loaded and running over. The output from August to November, inclusive, averaged 40 000 cu. yd. per month; one shift only was worked per day, and although the quantity was not large for three such powerful shovels, it was large to truck through the streets, and required that

SKETCH SHOWING TYPICAL BENT OF TRESTLE SUPPORTING EIGHTH AVENUE

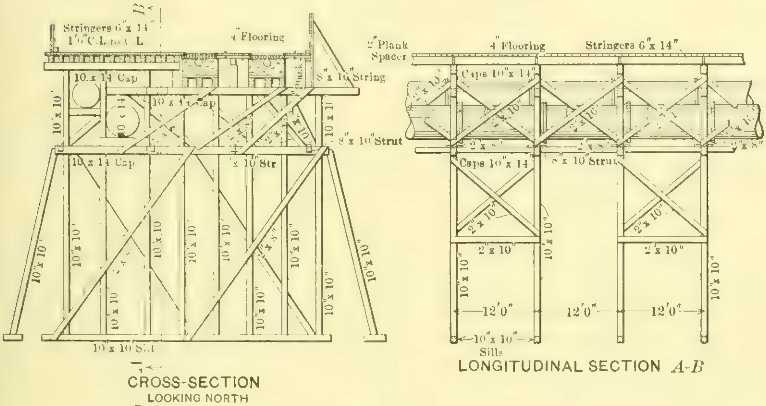


FIG. 9.

one team pass a given point every 18 sec. At the end of November the opening up of the pit had been accomplished, considerable rock had been stripped near Ninth Avenue, and the streets had become so icy that the cost of transportation was practically doubled; work in the pit, therefore, was much curtailed, and amounted to continuous work for one shovel from that time until the end of the period, May 22d, 1905, when Pier No. 72 was put in service and transportation by train began. Figs. 2 and 3, Plate LXIX, show the condition of the pit east and west of Eighth Avenue, respectively, on that date.

The work of excavating for and building the temporary street bridge, a typical bent and bracing for which are shown on Fig. 9, and the cast-iron sewer and water mains in Eighth Avenue, was com-

menced on September 3d, 1904. The trestle was a double-decked structure of yellow pine, with 10 by 10-in. posts and sills, 10 by 14-in. intermediate and top caps, and 2 by 10-in. longitudinal and cross-braces. The trestle was further stiffened longitudinally by four lines of 8 by 10-in. struts, butted between the intermediate caps, and held in position by 2 by 8-in. splice-plates resting on top of them. The intermediate caps were at an elevation of 15 ft. below the surface of the street, and above that line the longitudinal bracing was continuous, while below it the bents were braced in pairs, the bracing being omitted from every second bay. Below the intermediate cap the bents were uniform for the entire width of the trestle, but the top cap was not continuous, being 5 ft. below the surface under the trolley tracks, and only 18 in., the depth of stringers and planking, beyond. The stringers under the trolley tracks were 8 by 16-in. yellow pine, spaced three to a track, and those for the driveway were 6 by 14-in., spaced 1 ft. 6 in. on centers, the planking being 4-in. yellow pine.

The first step in the construction was to excavate a trench 15 ft. wide on the west side of the street, the east side of the trench being 4 ft. west of the westernmost trolley rail. While this work was in progress, all vehicular traffic was turned to that part of the avenue east of the westerly trolley rail. The trench was sheeted and timbered, and carried to a depth sufficient to receive the intermediate cap. That portion of the bent from the bottom of the intermediate cap to the bottom of the top cap was then erected for the width of the trench, after which the 60-in. cast-iron sewer and the 48-in. water main were laid in position and caulked. The top cap, stringers, and planking were then laid, for the full width of the trestle west of the trolley tracks. This work was finished and the sewage turned into the new sewer in April, 1905.

As the planking was laid west of the trolley tracks, traffic was turned to that side of the street, and the material east of the tracks was excavated to its natural slope. Trenches were then dug under the tracks on the line of the bents, and the caps were set in position on blocking. The material between these trenches was then removed, the tracks being supported meanwhile by blocking at least every 6 ft., and the stringers and planking were shoved into place. Excavation was next made between the caps to a depth of about 5 ft. below them, needle-beams being placed under the caps, one or two at a time, and

supported on posts erected in these excavations; the material on line of the bents was excavated to the depth of the intermediate caps, which were then set, together with the posts and bracing for the upper deck of the structure. This operation was repeated for the lower deck, about 10 ft. being gained for each change of posts, and three shifts, therefore, were required.

At the beginning of the train-transportation period, May 22d, 1905, two shifts of 10 hours each were inaugurated, and the earth was handled at the rate of from 85 000 to 90 000 cu. yd. per month; but, by the end of August, when a little more than 60% of the total earth had been disposed of, the rock began to interfere very greatly with the progress. The strike of the rock was almost directly north and south, and its surface formed broken ridges running in that direction, with deep valleys between. The dip was almost vertical near Ninth Avenue, and about 70° toward the west near Seventh Avenue. This condition made it necessary to turn the shovels parallel to the ridges in order to strip the rock for drilling; and, as the ridges were very broken, the shovels continued to bump into them on all occasions, making it necessary to move back and start other cuts or stand and wait for the rock to be drilled and blasted. One small Vulcan steam shovel, with vertical boiler and ¾-cu. yd. dipper, had been brought on the work to be used in stripping rock, and was moved from place to place so much more easily than the large ones that an Ohio shovel of the same general type was purchased in October, and thereafter the stripping was done largely by the two small shovels and by hand, the large shovels being used almost exclusively in handling rock.

The drilling necessary to remove the rock was very large in amount and also per yard excavated. In order not to damage the retaining walls and the rock underlying them, holes spaced at 5-in. centers were drilled 1 ft. away from the face of the walls and on the same batter. These breaking holes alone amounted to a total of 210 000 lin. ft., or 1 ft. of hole for each 3½ cu. yd. of rock excavated; and the regulations of the Bureau of Combustibles, which prevented springing, caused the blasting holes to be placed very close together and required a total of about 420 000 lin. ft., making 630 000 ft. If to this is added the block holes, for some of the rock broke very large, it will show at least 1 ft. of drill hole for each cubic yard of rock excavated, about ten times the average on general railroad work.

TABLE 1—(*Continued*).

21..........	172 + 12.0 172 + 45.2	271.48	31.75	10.80	2.50	0.85	8.65	251.18	311.50	1.24	5/29/05	6/3/05
22..........	168 + 41.3 168 + 72.6	316.30	44.00	14.97	5.25	1.79	7.18	292.36	338.75	1.16	6/5/05	6/10/05
23..........	173 + 63.6 174 + 04.5	529.33	54.75	18.63	4.75	1.62	1.25	507.83	587.25	1.16	6/5/05	6/13/05
24..........	167 + 92.6 168 + 41.3	1 010.64	66.00	22.46	5.50	1.87	10.16	976.15	1 038.75	1.07	6/8/05	6/21/05
25..........	173 + 21.2 173 + 63.6	675.21	77.75	26.46	2.50	0.85	12.00	635.90	776.25	1.22	6/16/05	6/24/05
26..........	164 + 72.5 165 + 05.8	458.22	40.00	13.61	5.50	1.87	22.37	420.37	532.00	1.26	6/23/05	6/28/05
27..........	172 + 81.9 173 + 21.2	409.43	35.00	11.91	9.75	3.31	4.64	389.57	450.00	1.16	6/27/05	7/7/05
28..........	164 + 27.6 164 + 72.5	658.46	72.00	24.50	1.50	0.51	16.40	617.05	726.25	1.18	6/29/05	7/7/05
29..........	172 + 45.2 172 + 81.9	345.89	30.25	10.29	5.00	1.70	1.62	332.28	384.00	1.16	7/11/05	7/19/05
31..........	174 + 78.0 175 + 18.5	507.50	35.75	12.17	3.00	1.02	17.09	477.22	567.50	1.19	7/29/05	8/6/05
32..........	174 + 29.6 174 + 78.0	396.99	43.75	14.89	1.75	0.60	6.50	375.00	434.25	1.16	8/5/05	8/12/05
43..........	177 + 94.0 178 + 44.1	194.07	30.00	10.21	2.00	0.68	8.35	174.83	219.75	1.26	11/9/05	11/12/05
Pier	168 + 72.6 168 + 81.1	106.52	......	......	......	......	......	106.52	144.00	1.35	12/6/06	12/8/06
76..........	178 + 44.1 178 + 94.1	136.32	12.75	4.34	4.75	1.62	......	130.36	142.50	1.09	7/8/07	7/10/07
79..........	178 + 94.1 179 + 44.1	118.07	9.00	3.06	3.50	1.19	......	113.82	129.50	1.14	7/15/07	7/16/07
82..........	179 + 44.1 179 + 93.7	126.12	6.50	2.21	2.50	0.85	......	123.06	131.75	1.07	7/22/07	7/23/07
84..........	179 + 93.7 180 + 44.2	126.77	6.75	2.30	2.25	0.77	......	123.70	133.50	1.08	7/26/07	7/27/07
86..........	180 + 44.2 180 + 93.6	162.48	8.00	2.72	2.75	0.94	......	158.82	167.00	1.05	7/30/07	7/31/07
90..........	180 + 93.6 181 + 17.9	92.52	4.00	1.36	1.00	0.34	......	90.82	115.00	1.27	8/18/08	8/18/08

NOTE.—The number of cubic yards of crushed stone used in any section can be found by multiplying the figure for that section in Column 10 by 0.7778.

The number of cubic yards of sand used in any section can be found by multiplying the sum of the figures for that section in Columns 4, 6, and 10 by 0.3889.

REMARKS.—Section No. 4. Amount of sand cut down on a part of this section on account of dust in stone.
Section No. 8. O'Rourke stone used on this section, large and full of dust.
Section No. 9. Stone crushed on the work used on this section, large and full of dust.
Section No. 21. 1 : 3 : 5 mix was used in part of this section on account of stone being large.
Section No. 24. Different sized stone was shipped on barge and mixed on the board for this section.
Section No. 25. 1 : 3 : 5 mix used in a small part of this section on account of stone being large.
Sections Nos. 76, 82, 84, and 86. Stone contained large amount of dust.

TABLE 1.—Record of Retaining-Wall Sections, Terminal Station.

West Thirty-first Street from Seventh Avenue to Ninth Avenue.

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
1..........	165 + 05.8 165 + 66.0	617.48	17.50	5.95	......	......	......	611.53	731.50	1.20	11/4/04	11/20/04
2..........	165 + 66.0 165 + 95.4	233.96	10.25	3.49	......	......	......	230.47	277.25	1.20	11/21/04	11/27/04
3..........	165 + 95.4 166 + 41.2	355.20	24.50	8.34	......	......	......	346.86	398.25	1.15	11/26/04	12/3/04
4..........	171 + 03.4 171 + 53.4	309.29	67.50	23.00	......	......	......	286.29	360.50	1.26	12/2/04	12/10/04
5..........	177 + 44.0 177 + 94.0	109.62	30.25	10.30	......	......	......	99.32	120.75	1.22	12/28/04	12/30/04
6..........	171 + 53.4 171 + 83.0	246.35	27.75	9.44	......	......	......	236.91	292.50	1.23	1/2/05	1/11/05
7..........	166 + 41.2 166 + 79.0	644.12	77.50	26.37	......	......	......	617.75	737.00	1.19	1/13/05	2/4/05
8..........	171 + 83.0 172 + 12.0	394.43	63.75	21.69	......	......	......	372.74	420.75	1.13	1/14/05	1/28/05
9..........	166 + 79.0 167 + 20.5	974.58	103.75	35.30	2.50	0.85	7.96	930.47	1 066.25	1.14	2/18/05	3/13/05
10..........	170 + 16.6 170 + 58.6	767.34	92.50	31.48	2.75	0.94	......	734.92	852.50	1.16	1/31/05	2/25/05
11..........	170 + 58.6 171 + 03.4	599.17	77.00	26.20	10.25	3.49	......	569.48	689.75	1.21	3/11/05	3/23/05
12..........	167 + 20.5 167 + 43.9	535.23	50.50	17.18	2.00	0.68	4.00	513.42	611.75	1.19	3/9/05	3/26/05
13..........	175 + 18.5 175 + 61.8	553.04	62.00	21.10	5.25	1.79	......	530.15	630.50	1.19	3/15/05	3/29/05
14..........	177 + 02.9 177 + 44.0	305.12	49.25	16.76	4.50	1.53	......	286.83	340.25	1.19	3/26/05	3/31/05
15..........	175 + 61.8 175 + 91.7	429.88	50.00	17.01	1.50	0.51	......	412.36	472.50	1.15	3/28/05	4/14/05
16..........	176 + 62.5 177 + 02.9	675.64	77.50	26.37	6.25	2.13	......	647.14	788.00	1.22	4/1/05	4/17/05
17..........	174 + 04.5 174 + 29.6	162.98	29.00	9.87	3.50	1.19	......	151.92	182.50	1.20	5/3/05	5/6/05
18..........	175 + 91.7 176 + 21.5	698.88	46.25	15.72	4.50	1.53	15.86	665.77	801.00	1.20	5/9/05	5/19/05
19..........	176 + 21.5 176 + 62.5	1 166.79	81.50	27.73	4.00	1.36	34.96	1 102.74	1 354.50	1.23	5/15/05	5/28/05
20..........	167 + 43.9 [illegible]	975.53	95.75	32.58	3.25	1.11	36.99	904.85	1 012.75	1.12	5/25/05	6/3/05

TABLE 2—(*Continued*).

49	177 + 81.1 178 + 24.1	241.51	25.25	8.59	2.50	0.85	1.33	230.74	274.00	1.19	5 21 06	5 24 06
50	168 + 03.6 168 + 45.6	405.61	25.50	8.68	4.00	1.36	36.10	359.47	406.00	1.13	6 13 06	6 18 06
51	177 + 39.4 177 + 81.1	100.54	12.75	4.34	3.00	1.02	0.78	94.40	112.00	1.19	6 20 06	6 21 06
52	168 + 45.6 168 + 80.1	181.96	19.00	6.47	1.00	0.34	9.03	166.12	190.00	1.14	6 25 06	6 28 06
53	168 + 80.1 169 + 00.1	41.32	3.50	1.19	......	......	......	40.13	44.50	1.11	6 29 06	6 29 06
55	176 + 90.0 177 + 38.4	92.41	11.25	3.83	2.50	0.85	3.68	84.05	98.25	1.17	8 17 06	8 18 06
56	167 + 62.1 168 + 03.6	383.67	33.75	11.48	3.25	1.11	36.62	334.46	383.50	1.14	8 28 06	9 1 06
59	175 + 67.3 175 + 98.9	175.61	15.50	5.27	2.50	0.85	9.37	160.12	186.00	1.16	10 15 06	10 16 06
60	176 + 49.0 176 + 90.0	69.97	8.25	2.81	3.00	1.02	1.58	64.56	75.00	1.16	10 17 06	10 18 06
61	175 + 98.9 176 + 49.0	104.56	8.00	2.72	3.50	1.19	3.72	96.93	108.00	1.11	10 19 06	10 20 06
64	175 + 30.3 175 + 67.3	140.15	14.75	5.02	2.75	0.94	......	134.19	161.50	1.20	11 21 06	11 22 06
65	174 + 85.4 175 + 30.3	80.66	9.00	3.06	2.50	0.85	......	76.75	92.75	1.21	12 14 06	12 15 06
66	174 + 47.9 174 + 85.4	68.89	5.50	1.87	3.25	1.11	......	65.91	83.50	1.27	12 18 06	12 18 06
67	174 + 21.1 174 + 47.9	60.14	3.00	1.02	2.00	0.68	0.92	57.52	67.50	1.17	12 21 06	12 21 06
68	167 + 12.3 167 + 62.1	379.94	23.50	8.00	5.00	1.70	19.34	350.90	412.50	1.17	1 2 07	1 6 07
69	173 + 85.6 174 + 21.1	77.43	6.50	2.21	3.00	1.02	......	74.20	91.00	1.23	1 29 07	1 30 07
70	166 + 75.6 167 + 12.3	408.81	33.75	11.48	3.75	1.28	......	396.05	468.50	1.18	4 2 07	4 10 07
71	173 + 46.5 173 + 85.6	85.92	8.25	2.81	1.75	0.60	......	82.51	95.75	1.16	4 17 07	4 19 07
74	172 + 19.2 172 + 73.0	449.28	22.75	7.74	6.25	2.13	......	439.41	506.00	1.15	6 20 07	6 24 07
75	172 + 73.0 173 + 24.0	502.20	27.25	9.27	7.00	2.38	......	490.55	579.00	1.18	7 8 07	8 25 07
77	164 + 77.0 165 + 27.1	141.38	9.00	3.06	7.25	2.47	......	135.85	161.50	1.19	7 13 07	7 15 07
78	168 + 83.4 169 + 18.3	63.35	3.00	1.02	1.50	0.51	......	61.82	73.00	1.18	7 13 07	7 14 07

TABLE 2.—RECORD OF RETAINING-WALL SECTIONS, TERMINAL STATION.

West Thirty-third Street from Seventh Avenue to Ninth Avenue.

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for [illegible]g.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
30..........	170 − 13.2 171 + 16.1	364.72	42.50	14.46	4.00	1.36	......	348.90	391.00	1.12	7/20 05	7 26 05
33..........	178 − 48.7 178 − 84.1	180.40	29.50	10.04	3.50	1.19	......	169.17	188.00	1.11	8 7 05	8 11 05
34..........	R 2 + 75.5 170 + 03.6	214.12	38.00	12.93	1.00	0.34	1.50	199.35	217.25	1.09	8 14 05	8 19 05
35..........	171 + 16.1 171 + 42.5	381.56	40.35	13.70	1.00	0.34	14.37	353.15	400.25	1.13	8 16 05	8 22 05
36..........	170 + 03.6 170 + 25.0	150.16	20.50	6.98	......	......	6.25	136.93	133.75	0.98	8/19 05	8 22 05
37..........	171 + 42.5 171 + 91.3	869.40	59.50	20.25	4.50	1.53	44.96	802.66	909.00	1.13	8 22 05	9 6/05
38..........	171 + 91.3 172 + 19.2	233.49	22.75	7.74	2.75	0.94	14.45	210.36	238.50	1.13	8 24 05	8/27 05
39..........	179 + 27.2 179 + 64.2	255.39	32.00	10.89	3.00	1.02	9.05	234.43	270.25	1.15	8/29 05	9/2/05
40..........	170 + 25.0 170 + 73.2	500.73	44.25	15.06	1.00	0.34	29.64	455.69	525.75	1.15	9 11 05	9/15 05
41..........	169 + 50.8 R 2 + 75.5	215.93	28.25	9.61	2.00	0.68	......	205.64	236.50	1.15	10 3 05	10 6 05
42..........	178 + 84.1 179 + 27.2	177.62	23.00	7.83	1.50	0.51	7.06	162.22	194.75	1.20	10 9 05	10 11 05
44..........	180 + 05.5 180 + 44.2	936.15	58.75	19.99	10.50	3.47	73.84	838.85	987.00	1.18	11/17 05	11/27/05
45..........	180 + 44.2 180 + 74.9	1 133.69	60.00	20.42	5.00	1.70	60.71	1 050.86	1 206.00	1.15	12 13 05	12 23 05
46..........	179 + 64.2 180 + 05.5	477.14	35.00	11.91	3.75	1.28	24.58	439.37	535.00	1.22	1 15 06	1 19/06
47..........	169 + 00.1 169 + 50.8	136.19	14.25	4.85	3.50	1.19	2.00	128.15	150.50	1.17	4 4 06	4 6 06
48..........	178 + 24.1 178 + 48.7	192.78	21.25	7.23	2.00	0.68	......	184.87	226.00	1.22	4 24 06	4 30 06

TABLE 2—(*Continued*).

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
80..........	165 + 27.1 165 + 76.6	108.86	11.75	4.00	3.00	1.02	......	103.84	133.50	1.28	7/18/07	7/19/07
81..........	168 + 45.6 168 + 83.4	210.97	13.00	4.42	6.25	2.13	......	204.42	255.75	1.25	7/20/07	7/23/07
83..........	165 + 76.6 166 + 20.5	108.06	8.00	2.72	3.75	1.28	......	104.06	128.50	1.23	7/25/07	7/27/07
85..........	166 + 20.5 166 + 64.6	107.52	9.00	3.06	2.25	0.76	......	103.70	144.50	1.39	7/29/07	7/30/07
87..........	166 + 64.6 166 + 75.6	23.44	1.00	0.34	1.25	0.42	......	22.68	30.00	1.32	7/31/07	7/31/07
88..........	164 + 26.3 164 + 77.0	317.72	24.00	8.17	2.25	0.76	......	308.79	370.00	1.20	8/8/07	8/11/07
89..........	173 + 20.8 173 + 40.5	93.51	5.00	1.70	1.50	0.51	......	91.30	121.75	1.33	9/7/07	9/8/07
91..........	180 + 74.9 180 + 92.7	141.40	17.50	5.96	......	......	......	135.44	203.50	1.50	11/18/08	11/20/08
92..........	180 + 92.7 181 + 28.8	118.93	19.00	6.46	......	......	......	112.47	190.00	1.69	12/1/08	12/2/08

NOTE.—The number of cubic yards of crushed stone used in any section can be found by multiplying the figure for that section in Column 10 by 0.7778.

The number of cubic yards of sand used in any section can be found by multiplying the sum of the figures for that section in Columns 4, 6, and 10 by 0.3889.

REMARKS.—Section No. 47. Part of this section was removed on account of damage done by blasting and was replaced by Section No. 78.
Section No. 52. All of this section was removed on account of damage done by blasting and was replaced by Section No. 81.
Section No. 53. All of this section was removed on account of damage done by blasting, and was replaced by Sections Nos. 78 and 81.

TABLE 3.—Record of Retaining Wall Sections.

Power-House.

(1) Section No.	(2) Stations.	(3) Contents of section, in cubic yards.	(4) Barrels of cement used for facing.	(5) Cubic yards of facing mortar equivalent.	(6) Barrels of cement used for bed mortar.	(7) Cubic yards of bed mortar equivalent.	(8) Cubic yards of embedded stone.	(9) Cubic yards of concrete in section (net).	(10) Barrels of cement used in concrete.	(11) Barrels of cement per cubic yard of concrete.	(12) Concrete started.	(13) Concrete finished.
A..........	2 + 75.3 3 + 25.3	463.28	58.25	19.82	5.50	1.87	11.50	430.09	482.75	1.12	5/18/05	5/25/05
B..........	3 + 25.3 3 + 74.9	114.78	23.00	7.83	1.75	0.60	1.50	104.85	125.50	1.20	6/14/05	6/16/05
C..........	169 + 30.8 169 + 74.8	179.19	34.25	11.66	1.00	0.34	3.60	163.59	183.00	1.12	7/10/05	7/13/05
D..........	169 + 74.8 170 + 28.8	114.38	27.25	9.27	0.25	0.09	0.07	104.95	119.25	1.14	7/14/05	7/19/05
E..........	168 + 83.6 169 + 30.8	101.20	22.00	7.49	1.50	0.51	0.65	92.55	107.25	1.16	7/26/05	7/28/05
F..........	2 + 78.2 3 + 19.6	358.80	39.50	13.44	0.75	0.26	9.50	335.60	397.75	1.18	9/19/05	9/24/05
G..........	3 + 19.6 3 + 56.9	237.33	23.00	7.83	1.00	0.34	0.74	228.42	278.00	1.22	9/26/05	9/29/05
H..........	3 + 56.9 168 + 83.6	25.55	6.25	2.13	0.75	0.26	......	23.16	28.00	1.21	9/29/05	9/29/05
						Seventh Avenue.						
54..........	164 + 27.6 L 2 + 32.0	764.48	69.75	23.74	3.00	1.02	......	739.72	907.50	1.23	8/6/06	8/15/06
57..........	L 2 + 10.3 L 2 + 32.0	533.06	34.00	11.57	2.25	0.77	......	520.72	610.75	1.17	9/10/06	9/15/06
58..........	L 1 + 87.1 L 2 + 10.3	544.54	32.25	10.97	2.00	0.68	9.80	529.09	588.25	1.11	9/24/06	9/28/06
62..........	L 1 + 87.1 L 1 + 64.4	575.67	30.00	10.21	3.00	1.02	26.20	538.24	639.50	1.19	10/24/06	10/29/06
63..........	L 1 + 42.4 L 1 + 64.4	607.01	30.50	10.38	2.50	0.85	13.79	581.99	678.50	1.17	11/5/06	11/11/06
72..........	L 1 + 42.4 L 1 + 19.6	631.97	30.00	10.21	1.75	0.60	1.18	619.98	719.50	1.16	4/25/07	4/30/07
73..........	L 1 + 19.6 L 0 + 97.0	573.33	25.25	8.59	0.25	0.08	2.48	562.18	685.75	1.22	5/13/07	5/18/07

Note.– The number of cubic yards of crushed stone used in any section can be found by multiplying the figure for that section in Column 10 by 0.7778. The number of cubic yards of sand used in any section can be found by multiplying the sum of the figures for that section in Columns 4, 6, and 10 by 0.3889.

Channeling with a 10-ft. quarry bar, carrying a No. 4 Ingersoll-Rand drill with Z-bits, was attempted in place of the close drilling below the walls, but, as the rock stood so nearly vertical and was full of soft seams, very little could be accomplished, the average cut per day of 10 hours, counting the time of moving and setting up, was only 4 sq. ft., and, after a thorough trial, the bars were abandoned.

Disposal.—The excavated material was hauled from the shovels to the pier in 10-car trains. The cars were of three classes: 4-yd. Western dump-cars, flat cars without skips, and flats carrying specially designed steel skips having a capacity of 4 cu. yd. each. As far as practicable, earth, and rock containing 1 cu. yd. or less, was loaded on dumpers, medium-sized rock on the skips, and large rock on the bare flats. As a steam shovel must pick up what is nearest to it first, however, this classification could not always be adhered to, and many large rocks were loaded into dumpers. Cars of this class which contained no material too large to dump were run at once to the hoppers, and were dumped and returned to the pit; others, together with the flat and skip cars, were run down the incline to the derricks and telphers, where the flats and skips were entirely unloaded, and the large rocks were removed from the dumpers, after which they were run to the hoppers and emptied.

The total quantity of excavated material handled at this pier from May 22d, 1905, to December 31st, 1908, amounted to 673 800 cu. yd. of earth and 1 488 000 cu. yd. of rock, place measurement, equal to 3 203 400 cu. yd., scow measurement; in addition to which 175 000 cu. yd. of crushed stone and sand and 6 000 car loads of miscellaneous building material were transferred from scows and lighters to small cars for delivery to the Terminal work.

All the earth and 570 000 cu. yd. of the rock, place measurement, were handled through the chutes, and the remainder of the rock, 918 000 cu. yd., and all the incoming material by the derricks and telphers. In capacity to handle material, one telpher was about equal to one derrick. A train, therefore, could be emptied or a boat loaded under the bank of eight telphers in one-fourth the time required by the derricks, of which only two could work on one boat. The telphers, therefore, were of great advantage where track room and scow berths were limited.

As noted in the list of contracts under which the work was exe-

cuted, the scows at both the 35th Street dumping board and Pier No. 72 were furnished, towed, and the material finally disposed of, by Henry Steers, Incorporated. During the same period, this contractor disposed of the material excavated from both the Cross-town Tunnels, constructed by the United Engineering and Contracting Company, and the tunnels under the East River, constructed by S. Pearson and Son, Incorporated. As stated in previous papers of this series relating to the construction of those tunnels, the material excavated by the United Engineering and Contracting Company was delivered to barges at 35th Street and East River and that by S. Pearson and Son, Incorporated, at two points, one in Long Island City and the other at 33d Street and East River, Manhattan.

The total number of cubic yards of material disposed of amounted to:

	Place measurement. Earth.	Place measurement. Rock.	Total barge measurement.
35th Street and North River	242 800	22 800	281 500
Pier No. 72, North River	673 800	1 488 000	3 203 400
From Cross-town Tunnels			570 400
From Under-river Tunnels			402 500
Total			4 457 800

The material was delivered as follows:

To the freight terminal of the Pennsylvania Railroad Company at Greenville, N. Y.	3 454 800
To the Meadows Division of the Tunnel Line between Harrison, N. J., and the North River Portals	711 900
To other points selected by the contractors	291 100
Total	4 457 800

The handling of this large quantity of material required the loading of from 10 to 20 scows per day (and for more than two years the average was 14), and, as the average time spent in one round trip was $3\frac{1}{3}$ days, a fleet of more than 50 scows was required to keep all points supplied and allow for a few to be out of service undergoing repairs.

All loaded scows were towed from the docks, with the ebb tide, to a stake boat anchored in the bay about one mile off shore at Greenville; and were taken from there to the different unloading points, as required, by smaller tugs which also returned the empty scows to the stake.

The unloading plants were similar at the different points, although that at Greenville was much larger than the others. It included five land dredges and eight traveling derricks of two types, one floating and the other mounted on wheels and traveling on a track of 16-ft. gauge. The derricks handled the large rock, which was loaded at Pier No. 72 by derricks and telphers. They were of the ordinary **A**-frame type, and were designed to handle 20 tons. They were operated by 9 by 10-in. Lidgerwood double-drum and swinging-gear engines. The large rock was deposited by the derricks either in the channels along which they worked or in the fill along shore, without the use of cars. The land dredges were equipped with a 60-ft. boom and a 2½-yd. Hayward bucket operated by a 14 by 18-in. double-drum Lidgerwood dredging engine. They loaded into 9-yd., standard-gauge, side-dump cars, built by the contractor, and unloaded the scows to within about 1 ft. of the deck, a Hayward bucket being unsuitable for closer work without greatly damaging the scows. The material remaining was loaded by hand into skips which were handled to the cars by small derricks, one of which was located at the rear of each dredge. The cars were taken to the dump and returned by 25-ton, standard-gauge, engines which had previously done service on the Manhattan Elevated Railroad, but were spotted for loading by the engine on the dredge.

In order to keep a record of the fleet of scows, which would show the available supply at a glance, a board, 10 by 15 in., and covered with a heavy sheet of ruled paper, was arranged as shown by Fig. 10. It was divided into 12 vertical columns, the first of which was headed "Scows," and contained the name or number of each scow in service. The next four columns denoted loading points, and were headed "Pier No. 72," "Thirty-third Street, East River," "Thirty-fifth Street, East River," and "Long Island City," respectively; the sixth column was headed "Greenville," the seventh "Hackensack," the eighth "Passaic," and the ninth "Governors Island," being unloading points, the tenth and eleventh, "Stake Boat" and "Dry Dock," respectively, while the twelfth was for "Extra pins," not in use. To indicate the condition of the scows, small pins with colored heads were used; white indicated empty; blue, working; black, loaded; red, being repaired; and a pearl-colored pin, missing. Thus a white-headed pin opposite the number 6 in the column headed Pier No. 72 indicated that scow No. 6 was lying at that pier waiting to be placed in position for

loading, whereas a black-headed pin at the same point meant that the scow had received its load and was ready to be towed.

The scows were all taken from the general service about the harbor; some of them were practically new, while others had seen much service. They were of two general types, truss-framed or bulkhead-framed; all were flat-bottomed, with a rake of about 45° at bow and stern. The truss-framed scows were built with a cross-truss every 10 to 15 ft., on which rested, fore and aft, two classes of beams, main and intermediate. The main beams were built of timbers ranging from 10 by 10 in. to 14 by 14 in., were scarfed at the joints, and trussed with the bottom logs. The intermediate beams were of timbers varying from

Scows.	Loading Points.				Unloading Points.				Stake Boat.	Dry Dock.	Extra Pins.
	Pier No.72	Thirty-third Street East R.	Thirty-fifth Street East R.	Long Island City.	Greenville.	Hackensack.	Passaic.	Governors Island.			
H.S. No.1											Empty.
H.S. No.2											
H.S. No.3											White Pins not in use placed here
H.S. No.4											
H.S. No.5											
H.S. No.6											
H.S. No.7											
H.S. No.8											

BOARD
RECORDING LOCATION
AND CONDITION OF SCOWS
FIG. 10.

6 by 6 in. to 10 by 12 in., had butt joints, and were dapped at the cross-trusses to give a convex surface to the deck, which was built of 3-in. and 4-in. plank, from 8 to 12 in. in width, running athwartship. The sides of the scows of this class were spiked and bolted to trusses similar to those running under the main beams. The bulkheaded boats had both sides and two longitudinal bulkheads placed so as to divide the scow into three sections of equal width, built of 8 by 8-in. or 10 by 10-in. timbers, laid one upon the other, and bolted through from top to bottom. The beams on these boats ran athwartship, rested on sides and bulkheads, and ranged from 6 by 10-in. to 10 by 12-in., spaced 2 ft. apart, and dressed to give a convex surface to the deck, which

was usually 3 in., in some cases 4 in., in thickness, and made up of narrow plank from 4 to 6 in. in width.

These boats had all been designed for lighter work than they were here required to perform, and a large amount of breakage occurred from the start. In order that the contractors for the excavation should

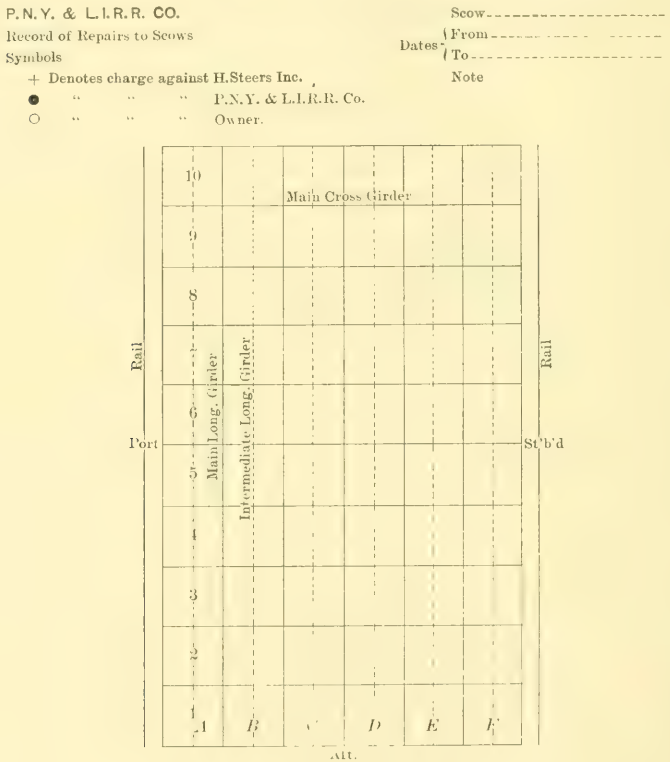


DIAGRAM OF DECK SHOWING BAYS

FIG. 11.

be unhampered as to method of loading, the contracts provided that they should pay for all damage done to the scows in loading, other than ordinary and usual wear and tear, all other damage being at the expense of the contractor for the disposal. A rigid system of inspection was necessary to determine and record properly the damage for which each contractor was responsible; and, as much of the breakage could not be noticed from the exterior, a thorough examination of the interior of each scow was made before and after every loading. In

order to keep proper records, the bays of each scow, formed by the cross-trusses, were numbered, beginning aft with number 1 and going forward to the bow, and the longitudinal bays formed by the main beams were lettered, beginning with *"A"* on the port side. A beam broken in "1-*A*," therefore, would be an intermediate beam in the stern port corner bay, and a beam broken in "10-*A*-*B*" would be a main beam at the bow end on the port side. The underside of each plank was marked with a number beginning with 1 at the stern and increasing by unity to the bow. Fig. 11 is a diagram of a scow in accordance with this system. In addition to recording the date, location, extent, and party responsible for each damage, in a book kept for that purpose, the injured member was marked with paint, the color of which indicated the party responsible. The repairs were made by the contractor for the disposal of material, and the cost was assessed according to the marking in the boat.

The careful inspection of the damage done to scows and the cost of their repairs enables a fairly accurate statement to be made of the amount at different points, and it is here given on the basis of cost of repairs per cubic yard, barge measurement, of material handled.

	Cost, in cents per cubic yard.
Repairs of damage done in loading material from the terminal site	2.00
Repairs of damage done in loading material from cross-town tunnels	1.32
Repairs of damage done in loading material from under-river tunnels	1.77
Repairs of damage done in transporting and unloading material from all points	1.81

The above figures do not include the expense due to scows which were overturned or sunk while in the service, which amounted to 0.4 cent per cubic yard, additional.

Ninth Avenue Tunnels.—The two double-track tunnels under Ninth Avenue, constructed to obtain 100 ft. of additional tail room on each of four tracks, required an excavation 76 ft. wide, Fig. 12. The rock, although fair, was not firm enough for so great a span, and, to obviate the necessity of timbering, the center wall was built before excavating

for the full width. The dip of the rock at this point is almost 90°, and to prevent blowing away the entire face in excavating for the tunnel, the pit excavation was not carried west to the final face below the springing line, a 10-ft. bench being left at that elevation. A top heading 9 ft. high and 10 ft. wide was started above that bench and, after penetrating about 10 ft., was widened to 20 ft. A cross-heading was driven in each direction at the west end of the first heading; the bench was then shot down, and the first 10 ft. of the longitudinal heading was widened sufficiently to receive the center wall, Fig. 12. After the middle wall had been concreted, any voids between its top and the rock

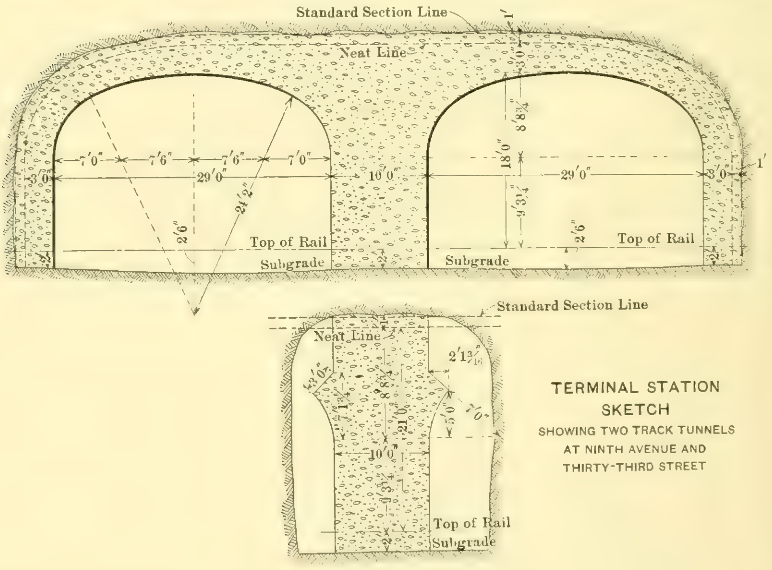


Fig. 12.

were grouted through pipes left for that purpose; the wall was then protected by curtains of heavy round timber securely wired together, and the remainder of the excavation was made by widening the cross-headings toward the face. The muck was carried out by two cableways, one on each side of the completed middle wall, each of which was supported by a tower outside of the tunnel and a large hook-bolt grouted into the rock at the inner end of the tunnel. Forms were built for each tunnel complete, and the concrete was delivered by a belt conveyor, running over the top of the lagging, and moved out as the tunnel was keyed.

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PAPERS AND DISCUSSIONS

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THE WATER SUPPLY OF THE EL PASO AND SOUTHWESTERN RAILWAY FROM CARRIZOZO TO SANTA ROSA, N. MEX.

By J. L. Campbell, M. Am. Soc. C. E.

To be Presented May 4th, 1910.

Location.—The El Paso and Southwestern Railway traverses the arid country west of the 100th Meridian in New Mexico, Texas, and Arizona, as shown on the map, Fig. 1. The water supply herein described serves that division of this road lying between Carrizozo and Santa Rosa, a distance of 128 miles.

Rainfall.—The average annual precipitation is 9.84 in. The year 1909 was exceptionally dry, with a rainfall of less than 5 in.

Original Water Supply.—East and west of El Paso, for distances of 270 miles in each direction, the railway crosses no streams, and the supply was obtained from wells ranging from 100 to 1 100 ft. in depth. On the division served by the new supply, this well-water is of very bad quality, as shown in Table 1.

After the most thorough practicable treatment, these waters were still so bad that they caused violent foaming, low steam pressure, hard scaling, rapid destruction of boiler tubes, high coal and water consumption, extraordinary engine failures and repairs, small engine

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

mileage, low train tonnage, excessive overtime, and a demoralized train service.

TABLE 1.

Station.	Incrusting solids, in grains per gallon.	Non-incrusting solids, in grains per gallon.
Carrizozo	31	7
Ancho	14	14
Gallinas	91	8
Varney	180	14
Duran	127	55
Tony	115	11
Pastura	141	6
Pintado	81	9
Santa Rosa	140	29

New Water Supply.—The writer was directed to find, if possible, a supply of good water, and his efforts proved successful. The pure water now in use has eliminated the adverse conditions before mentioned; has improved the *esprit de corps* of the train service; and, in a short time, the reduction in operating expenses will liquidate the first cost of the new supply.

This supply is taken from the South Fork of Bonito Creek, which flows down the eastern slope of White Mountain. The latter is 12 000 ft. high, and is 16 miles south of Carrizozo (Fig. 1). The watershed is a granite and porphyry formation, heavily timbered, and the stream is fed by snow and rain. This combination yields an excellent water, carrying on an average 6.05 grains of incrusting and 0.95 grains of non-incrusting solids per gallon. The North Fork of the creek carries 16.60 and 2.40 grains, respectively. Below the junction of these forks, the water contains 10.48 grains of incrusting and 1.57 grains of non-incrusting solids per gallon; and a branch pipe line takes water from the creek during intervals in dry years when the daily flow of the South Fork is less than the consumption.

The Water Plant.—The water is taken to and along the railway in pipe lines. The system includes 116 miles of wood pipe, 19 miles of iron pipe, one 422 000 000-gal. storage reservoir, four 2 500 000-gal. service reservoirs, two pumping plants in duplicate, and accessories of valves, stand-pipes, etc.

From a small concrete dam across the creek at an elevation of 7 728 ft., the pipe line drops down the narrow valley eastward, 5½ miles, to an elevation of 6 980 ft., where it turns abruptly north, rising in

1 mile to a table-land, 7 215 ft. above sea level, across which it continues northward 5 miles to the storage reservoir, which is on the north edge of this elevated country. Hereafter, this reservoir will be called the Nogal Reservoir, from the old mining village of Nogal lying $1\frac{1}{2}$ miles to the north and 600 ft. below it. From this reservoir, the line drops abruptly to the Carrizozo plain, and crosses the latter northward

FIG. 1.

to Coyote, at Mile 156, on the railway, at an elevation of 5 810 ft., passing, on the way, 6 miles east of Carrizozo, to which a branch pipe runs, Carrizozo being 5 430 ft. above sea level. There is a 2 500 000-gal. reservoir at Coyote, and a similar one at Carrizozo.

This describes the gravity section of the line which brings the water from the mountain stream to the railway. From Nogal Reservoir to

the latter, the capacity of the pipe is equal to the future daily requirements; from the source of supply to the reservoir, the pipe has twice as great a capacity, thereby storing surplus water. This section is 32 miles long, with a 6-mile branch line.

The second, or pumping section, extends eastward along the railway, rising from an elevation of 5 810 ft. at Coyote to 6 750 ft. on the Corona summit, which is the water-shed line between the Rio Grande on the west and the Rio Pecos on the east. At Coyote a pumping station lifts the water to Luna Reservoir and the pumps at Mile 171, and the latter lift it to the reservoir on Corona summit at Mile 192½. This section is 36½ miles long.

The third, or gravity section, extends from the reservoir on the Corona summit to the Rio Pecos at Mile 272, dropping from an elevation of 6 750 to 4 570 ft. in 80 miles. The pipe line extends to Pastura, 58½ miles from Corona, as shown on Plate LXX.

Where the pipe line passes a water tank on the railway, a 4-in. branch pipe is carried to the bottom of the tank and up to the top, where it is capped by an automatic valve. A gate-valve is placed in the branch pipe at its junction with the pipe line.

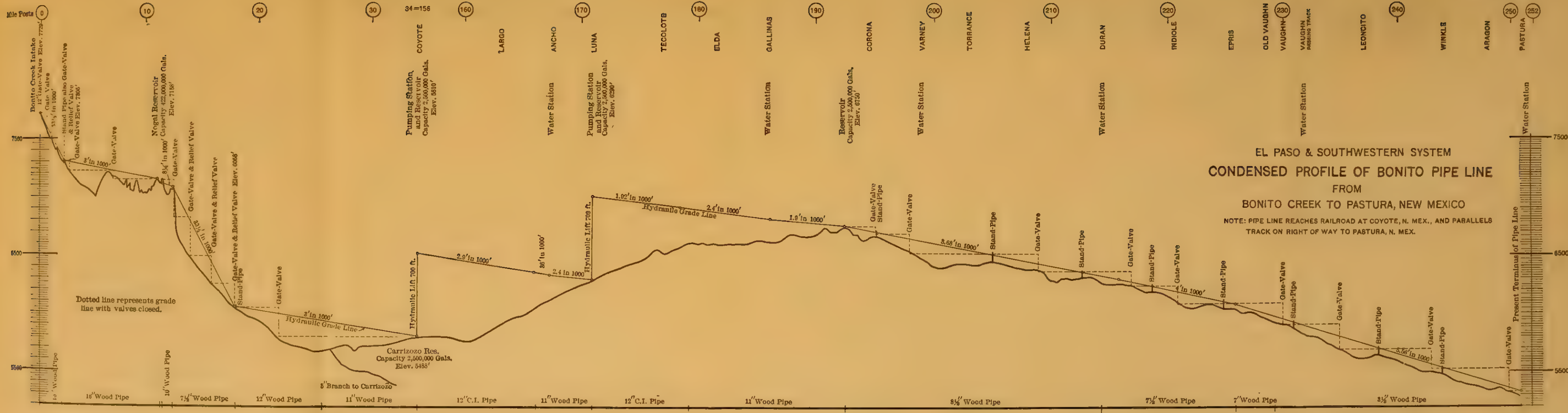
There are regulating, relief, check, blow-off, and air-valves, air-chambers, and open stand-pipes on the line, too numerous to mention in detail. They are designed to keep the wood pipe full, regulate flow, prevent accumulation of pressure and water-hammer, and remove sediment.

Water Pipe.—A study of the profile developed a system of hydraulic grades, pipe diameters, and open stand-pipes limiting the pressure to 130 lb. per sq. in., except on 19 miles of the pump main between Coyote and Corona where the estimated maximum pressure is 310 lb.

Investigation justified the assumption that wood pipe under a pressure of 130 lb. would give satisfactory service for 25 years, on which basis it would be less expensive than cast iron, and therefore it was used. Cast iron was considered preferable to steel for pressures not exceeding 310 lb. on account of its greater durability.

Wood Pipe.—Machine-made, spirally-wound, wood-stave pipe, made in sections from 8 to 12 ft. long, with the exterior surface covered with a heavy coat of asphalt, was selected in preference to unprotected, continuous, stave pipe. The diameters were not so great as to require the latter.

PLATE LXX.
PAPERS, AM. SOC. C. E.
MARCH, 1910.
CAMPBELL ON
RAILROAD WATER SUPPLY.



The first 40 miles of wood pipe was furnished by the Wykoff Wood Pipe Company, of Elmira, N. Y., and the Michigan Pipe Company, of Bay City, Mich., delivered the remaining 76 miles.

The pipe is wound with flat steel bands of from 14 to 18 gauge and from 1 to 2 in. wide. The machine winds at any desired pitch and tension. At each end the spiral wind is doubled two turns, the second lying over the first and developing a frictional resistance similar to that of a double hitch of a rope around a post. The ends of the band are held by screw nails or a forged clip, the latter being the better. It has two or three spikes on the under side which seat into the stave, and two side lugs on top which turn down over the band. The latter passes twice over the seat on the clip, the first turn holding the clip to the stave, while the second turn is held by the lugs which are hammered down over it. The end of the band is then turned back over the clip and held down by a staple.

The staves are double-tongued and grooved and from 1⅝ to 2 in. thick. The smaller thickness is sufficient. The exterior face of the staves should be turned concentric with the axis of the pipe and form a circle, so that the band will have perfect contact with the wood.

The joints are formed by turning a chamber in one end of the pipe and a tenon on the other, or both ends are turned to a true exterior circle and driven into a wood or steel sleeve. The chamber and tenon were used in this work.

Finally, each piece of pipe is covered with as much hot asphalt as it will carry.

Steel Bands.—The specifications required bands of mild steel, of 60 000 lb. strength, with an elastic limit half as great. The winding was spaced to limit the tension to 15 000 lb. per sq. in. If severe water-hammer is present, the ordinary working stress should be materially less than the latter, otherwise the spiral bands will stretch enough to permit the water to spurt out between the staves. This was determined to be true on 4 500 ft. of 12-in. pipe connecting the Carrizozo Reservoir with a water column at the roundhouse there. In pumping tests at the mills, attempts were made, at various times, to burst the pipe, but they never succeeded. Before the elastic limit was exceeded, the water was running out between the staves as fast as the pump forced it in. On the following day, pipe thus tested would carry the pressure for which it was designed without leaking. Except for defects in the band, pipe

of this kind will not burst in the service for which it is properly designed. This is true, without exception, of the 100 000 pieces of pipe in this service.

There has been some trouble with a number of the riveted splices on the banding. Such a splice occurs for every spool of banding used. In every case where one of these splices has pulled apart, the break was the result of defective riveting, permitting the rivets to pull out. In no case has a rivet been found sheared off, and even one good rivet appears to be sufficient to prevent rupture. The explanation is found in the high frictional resistance between the band and the pipe, which distributes the weakness of a bad splice over several adjacent turns of the band around the pipe. The band loosens a few turns only on either side of a parted splice, generally not more than three. In no case has any pipe been removed from the trench, repairs being made without interruption to the flow of water.

It is desirable to substitute welding for the riveting of these splices. The trouble is not present with the round band, the wrapped splice of the latter giving practically 100% efficiency.

The flat band was chosen for this work because it is the more effectively buried in and protected by the asphalt, and will not crush the soft wood staves under high pressure. The longevity of either the flat or the round steel band is dependent primarily on effective protection against contact with corrosive elements. Wrought iron should be used for this kind of service, and, for the same reason, for many other purposes. Engineers and consumers should join in some comprehensive and effective plan to bring back the old-time production of high-grade wrought iron.

Wood Staves.—The staves of this pipe are of Michigan and Canadian white pine. This pine cannot now be had of clear stuff or in long lengths in large quantities; otherwise, it is unexcelled. Douglas fir and yellow pine, coarser and harder woods, have the advantages of clear lumber and long length. Cypress is not as plentiful, and redwood is costly. The mill tests did not determine definitely the minimum degree of seasoning necessary, and press of time compelled the acceptance of some rather green lumber. Service tests do not show that there is any abnormal leakage from pipe made of such lumber, and it could not now be distinguished in the trench by such tests. Undoubtedly, however, thorough air seasoning should be required.

Bored Pipe.—Owing to its small size, a part of the $3\frac{1}{2}$-in. pipe was bored from the log. This was a mistake, for bored pipe has a rough interior and a reduced capacity. The inspection and culling are difficult and unsatisfactory, and imperfections readily apparent in a stave frequently escape detection in bored pipe.

Pipe Joints.—The chamber and tenon of this pipe is an all-wood joint, 4 in. deep. An iron sleeve makes a better and stronger joint. It compensates for any lack of initial tension in the banding over the chamber of the wood joint, and secures full advantage of the swelling of the wood. Cast iron is better than steel; it is more rigid, and its granulated surface breaks up the smoothness of the wood surface swelling against it. One objection to the cast-iron sleeve is that of cost, but it adds 4 in. to the effective length of every section of pipe, as compared with the wood joints. On the Pacific Coast, a banded wood-stave sleeve is used with success.

Coating.—To preserve the banding from corrosion and the wood from exterior decay, the pipe is thoroughly enveloped in refined asphalt having a flow-point adjusted to the prevailing temperature during shipment and laying. One grade can be used through a considerable range of temperature. This coating endured a 2 000-mile shipment successfully. Each piece was carefully inspected along the trench, and any break in the coating was thoroughly painted with hot asphalt. Enough of the latter came in barrels, with the pipe, from the factory.

The first 37 miles of this pipe has been in service for two years. Recent inspections show the coating to be in excellent condition and the steel underneath to be bright and clean. In some cases, where the initial pressure and leaking between the staves of the dry pipe were great, the escaping air and water lifted the coating into bubbles. At some points where this lifting was great enough to rupture the asphalt, and the soil is heavily charged with alkali, some corrosion has begun.

The integrity and impermeability of this asphalt coat are quite as vital as constant saturation. This coating protects the entire pipe from exterior contact with destructive agencies. With such effective exterior protection, a constantly full pipe is not so imperative. In the exterior protection of the wood, this coated pipe has quite an advantage over continuous stave pipe.

Each piece of pipe goes directly from the winder to the asphalt rolls, then to an adjacent saw-dust table, then back to the rolls, then

to the table again, and then to the dry finishing rolls at the opposite end of the table. The coating thus consists of two layers of asphalt and two of saw-dust. When the pipe leaves the finishing rolls, the coat is hard and smooth and about $\frac{3}{16}$ in. thick. This describes the coating as done at Bay City, Mich.

At Elmira, N. Y., one application of asphalt and saw-dust only, without a finishing dry roll, completed the work; but the band was run through a bath of hot asphalt as it was wound, thus coating its underside also. This initial treatment of the band on the Wykoff pipe is necessary because the exterior of the stave is neither planed nor turned to a circle. The exterior of the pipe forms a polygon, and the band is in perfect contact only at the angles. The theory in regard to the Michigan pipe is that the perfect contact of the band and the wood on the true exterior circle excludes air from the under surface of the metal, and prevents corrosion. Experience appears to justify this theory.

Cast-Iron Pipe.—Beginning at the first pumping plant at Coyote, at Mile 156, and running up to Mile 166, and again commencing at the Luna pumps, at Mile 171, and extending up to Mile 179, the minimum pressure on those portions of the pump main is more than the 130 lb. per sq. in. allowed for wood pipe, and the final estimated maximum pressures run up to 310 lb.

The selection of iron pipe for these pressures was, first, as between steel and cast-iron; and, second, as between the lead joint of the standard bell and spigot pipe and the machined iron joint of the universal joint pipe. Again, the choice was as between lead and leadite for the bell and spigot pipe.

Cast iron was selected because of the certainty of its long life, and the bell and spigot pipe was selected on the basis of comparative costs for pipe laid. The standard lead joint was chosen on the result of tests. This cast-iron pumping main has a diameter of 12 in. throughout.

Pipe Weights.—Makers of standard bell and spigot pipe urged the usual heavy weights selected for municipal service and heavy water-hammer. Three pressures, *viz.,* 217, 260, and 304 lb., were used for the division of pipe weights, on which the standard pipe-makers specified shell thicknesses of 0.82, 0.89, and 0.97 in. Eliminating water-hammer and adopting a working stress of 2 400 lb., the thick-

nesses are reduced to 0.54, 0.65, and 0.76 in. To make the latter conform to the specifications of the New England Water-Works Association, the pipe was cast to 0.57, 0.65, and 0.77 in. The reduction in cost amounts to $52 811.

By the provision of air-cushions, hereafter described, the writer's anticipation of no water-hammer on the pumping main has been fully realized.

The pipe was manufactured and inspected under the above-mentioned specifications.

Pipe Joints.—There was a question about the reliability of the lead joint at 300 lb. The writer had a section of 12-in. pipe, with standard joints containing 22 lb. of lead, laid and tested to 500 lb. without sign of failure or leakage. The joints were caulked down $\frac{3}{16}$ in. below the face of the bell. Of 8 700 joints thus made in the field, not one has blown out or failed. A few weeped slightly on top, and they were made permanently tight by additional caulking. The present maximum pressure is 278 lb. These joints are the standard joints specified by the New England Water-Works Association. It should be borne in mind that there is no water-hammer on this line. In 8 700 joints, 198 000 lb. of lead and 3 200 lb. of oakum were used, or 22.76 and 0.37 lb. per joint.

Leadite was tested in competition with lead, but it leaked at 100 lb. and failed under a sustained pressure of 300 lb. It is a friable material, and cannot be caulked successfully. Its principal ingredient appears to be sulphur. The failure was by slow creeping out of the joints. It is melted and poured, but not caulked. It has attractive features for low pressures and for lines not subject to movement or heavy jarring.

Air-Cushions.—To prevent water-hammer on the pumping main, all pumps are provided with large air-chambers. In addition, and as the special feature for absorbing the shock of pumping under high pressure through a pipe 21 miles long, a large air-chamber in the form of a closed steel cylinder, 5 ft. in diameter and 15 ft. long, is mounted on the pumping main outside of the pump-house. This cylinder is set on its side, in concrete collars, directly over the pipe beneath, to which it is connected by a 12-in. tee, in which a 12-in. gate-valve is set. The cylinder is provided with a glass gauge, cocks, etc. It was designed for a working pressure of 300 lb., and, at each pumping plant, it has proved to be entirely air- and water-tight. As indicated by sensi-

tive gauges on the pump main, just beyond these large air-chambers, the latter absorb all the water-hammer which gets beyond the air-chamber on the pumps.

Air-Pumps.—Each pumping plant is provided with four automatic air-charging devices, connecting to all air-chambers of the pumps and to the air-chamber on the pumping main. They are of the Nordberg type, and have proved very efficient. They are operated only a part of the time; otherwise, they accumulate too much air in the chambers.

Air-Valves.—On the entire line there are 144 automatic air-valves made by the United States Metal Manufacturing Company, of Berwick, Pa. They are working satisfactorily.

Gate-Valves.—In addition to the customary gate- and check-valves at the reservoirs and pumping stations, gate-valves are located at necessary points and elevations in the line to control the flow of water and keep the pipe full, even to the extent of closing all such valves tight and holding the line full without flow. This is for the purpose of delivering through a full pipe any desired quantity of water less than that required to keep the open pipe full. This, of course, is on account of the wood pipe. As the differences of elevations are very great on the gravity sections of the line, and as any one valve might inadvertently become closed tight when other valves above would be open, the bursting of the pipe under such conditions is prevented either by a pressure relief valve attached to and immediately above the gate-valve, or by an open stand-pipe erected on some suitable elevation between the valves. This is more clearly shown on the profile, Plate LXX, of the ground line and the hydraulic grades of the pipe line. An inspection of this profile will show that these controlling valves are located so that, when closed, the pressure against them does not rise above the maximum pressure on the section above, due to the hydraulic grade of the line when carrying its full capacity.

Safety Valves.—To prevent rupture of the pipe or injury to the pumps, in case the pumping mains should become obstructed, a 6-in. pop safety valve is mounted on the main just beyond the large air-chamber already described. These valves are set to release at the maximum working pressure of the pumps when the regular quantity of water is being pumped, and they are piped to the adjacent reservoir, so that there is no loss from them.

Check-Valves.—Check-valves are placed in the pumping main to prevent the backward flow of water. There is one near the pumps,

and one at the upper end and outside of the reservoir into which the main discharges.

Blow-Off Valves.—These valves are located in all material valleys or depressions.

Stand-Pipes.—Between the gate-valves, at certain points where the maximum hydraulic grade is not more than 60 ft. above the surface of the ground, open stand-pipes are erected. If the grade line is too high, relief-valves are used, as stated. Also at two points, where a steep grade ends near the ground surface and is followed by a flatter grade, stand-pipes are erected.

These stand-pipes are of 6-in. iron pipe standing in a special casting in the pipe line and enclosed in a concrete base. They are, of course, open at the top, and vary in height from 15 to 60 ft., depending on the elevation of the hydraulic grade. They have given some checks on the position of this grade during the velocity measurements hereinafter described. Their locations are shown on the profile, Plate LXX.

Nogal Reservoir.—Nogal Reservoir is the storage unit of the system, and is on the north edge of a table-land, 1 700 ft. above the railway, on the Carrizozo plain, 15 miles away. It is 11½ miles from the head of the pipe on Bonito Creek.

This reservoir is a natural basin or bowl, ½ mile in diameter across the top, ¼ mile on the bottom, and 36 ft. deep. A level line, 1 500 ft. long, drawn from its bottom, comes out to grade on the north declivity of the table-land. On this level line an open cut was made and the outlet pipe laid. The cut was then closed by a dam.

The supply pipe from Bonito Creek delivers water into the basin over the top of its southern rim, the water, as it leaves the pipe, flowing over a standard weir, without end contractions, into a stone gutter. A by-pass pipe, with suitable valves, passes around the western side of the basin and connects to the outlet pipe.

This comparatively small amount of work equipped a very good natural reservoir with a capacity of 422 000 000 gal., which can be increased to 1 000 000 000 gal. by embankments across low places in the rim.

Service Reservoirs.—At Coyote, an artificial service reservoir, 100 by 200 ft. on the bottom, with slopes of 1½ on 1 and a total depth of 15 ft., serves as an equalizer of the flow to and away from the pumps at that point. The pump-house is built alongside this reservoir.

The delivery pipe from the Nogal Reservoir runs directly to the pumps, but has a tee-branch, 50 ft. long, into the Coyote Reservoir. This branch passes through a valve chamber between the pump-house and the reservoir. In this chamber there are controlling valves and an automatic overflow. This overflow is provided against the contingency of a full reservoir and idle pumps. If the pipe line is delivering water faster than the pumps discharge it, the surplus goes into the reservoir. This arrangement is self-acting and controlling. There is a similar arrangement at the Luna pumping plant, also at the Carrizozo service reservoir, and at the regulating reservoir on the Corona summit.

Each of the four service reservoirs is of the same size, and lined with 4 in. of 1:2:4 concrete. At Luna and Corona the concrete is reinforced with $\frac{3}{8}$-in. round rods spaced 12 in. from center to center, both ways. This reinforcement should have been used in all the work.

Pumping Plants.—The pumps at Coyote and Luna are Nordberg duplex, cross-compound, condensing, crank-and-fly-wheel machines, with 6-in. plungers, traveling 600 ft. per min. at full normal speed, and designed to work against 300 lb. per sq. in. They have a guaranteed efficiency of 135 000 000 ft-lb. per 1 000 lb. of steam at 150 lb. and superheated 75 degrees.

The boilers are 125-h.p., Sterling, water-tube, with Foster superheaters, and 33-in. stacks, 100 ft. high.

Each plant is in complete duplicate pump and boiler units, only one set working at a time.

The pump building is a substantial concrete, brick, and steel structure, 50 by 80 ft. in plan, with a fire-wall, with two steel doors dividing the floor space into an engine-room 50 by 50 ft., and a boiler-room 50 by 30 ft. A concrete coal-bin adjoins the exterior boiler-room door. Coal is delivered directly from the car to the bin.

The plant is lighted by a small, but very complete, engine and dynamo on one base and run by steam from the Sterling boilers.

The two plants are exactly alike throughout.

Reservoir Leakage.—The Nogal Reservoir basin is covered with from 2 to 5 ft. of good clay, except where it is punctured by a dike, or washed down to the underlying sandstone by a few gullies. These punctures or washes were covered or filled with clay from 1 to 4 ft. deep. During the first season the leakage, above the 6-ft. contour, was at the rate of 2 in. per day.

As the water fell, due to leakage, evaporation, and use, a herd of from 300 to 400 cattle were worked around the shore line. This reduced the leakage to $\frac{3}{8}$ in. below 8 ft., and to nothing below 6 ft., above the outlet. As the flow line rises higher each season, the puddling will be continued to the top. The leakage at 12 ft. above the outlet, or 17 ft. above the bottom, is still approximately 1 in. per day. The total puddling, to date, covering two seasons, is equivalent to 11 150 days' work of one cow, and covers an area of 1 500 000 sq. ft.

The clay packed densely, the final hoof marks being not more than $\frac{1}{4}$ in. deep and remaining distinct under the water around the shore line for one year. Apparently, the reservoir will finally become water-tight at all elevations.

The soil in which the four service reservoirs on the railway are built proved to be about the worst for such work. In its natural state on the prairie, after the excavation for the reservoir was completed, it filtered water at the rate of 3 ft. per day. Tamping and puddling still left a filtration of 12 in. per day, with a tendency to increase. Enough water filtered through the concrete to produce settlement and cracks. Finally, the concrete was water-proofed with two coats of soap, two of alum, and one of asphalt. This has made all the reservoirs water-tight. Elaterite, an asphalt paint made by the Elaterite Paint and Manufacturing Company, of Des Moines, Iowa, was used successfully on the Luna Reservoir. This paint is applied cold, and preliminary tests showed it to be quite efficient.

The analysis of the soil is as follows:

Loss on ignition	3.35
Silica	56.36
Oxide of iron	2.93
Oxide of aluminum	8.97
Calcium oxide	15.95
Magnesium oxide	0.98
Oxides of sodium and potassium	0.47
Carbonic acid	11.35
Sulphuric acid	0.11
Chlorine	0.04
Manganese	Traces
	100.51

Insoluble matter, 64.50 per cent.

Pipe-Line Leakage.—There is no measurable leakage from the iron pipe. By thorough inspection and measurement at the end of two years, leakage on the wood pipe, between Coyote and Bonito Creek, from the 11- and 12-in. pipe, was found to be as follows:

On 8.6 miles,	11-in. pipe,	146 600 gal.	per day	=	17 046 gal.	per mile.
" 4 "	12 " "	14 829 "	" "	=	3 702 "	" "

The $7\frac{1}{2}$-in. pipe on this section appears to be leaking less than the 12-in. pipe. Inspection and measurement of it are to be made in a short time.

There is no material leakage from the 10- and 16-in. pipe between Bonito Creek and Nogal Reservoir, as determined by velocity and volumetric measurements hereafter described. The greatest probable error in the velocity measurements would not exceed $\frac{1}{2}$ per cent. If such error existed, and was all charged to leakage, it would amount to but 17 204 gal. per day, or 1 582 gal. per mile, out of a daily delivery of 3 784 000 gal.; but the measured discharge of the pipe, as determined by the velocity, was 5.84 sec-ft., while the mean maximum volume of this water over the weir at the end of the pipe is recorded by the weir as 5.88 sec-ft.

From Coyote, east along the railway, the wood pipe is remarkably tight. The rate of leakage from it, as determined by 600 observations uniformly distributed, was as follows:

11-in. pipe	=	120 gal. per mile per day.
$8\frac{1}{2}$- and $7\frac{1}{2}$-in. pipe	=	268 " " " " "

The maximum rate on 1 mile was 1 613 gal. The minimum found was zero.

The observations were made by uncovering a joint and measuring the leakage therefrom for 10 min. A graduated glass measuring to drams was used. The rate of leakage varied from 5 drops to 45 oz. in 10 min. Of the joints uncovered 57% was found to be leaking. It is rather remarkable that, in the large leakage of the 11- and 12-in. pipe between Coyote and Bonito, only one out of every eight joints was leaking. This indicates a physical defect in such joints. The largest leak found on one joint was at the rate of 17 280 gal. per day. Leakage between or through the staves is not measurable, as it is not fast enough to come away in drops unless there is some imperfection in the wood.

The insignificant leakage of 120 gal., stated above, is from the

11-in. pipe in the pumping main between Coyote and Corona. The present maximum working pressure on it is 100 lb. per sq. in. All the figures given above include visible and invisible leakage, the latter being such as does not appear on the surface. The visible leakage is but a small part of the total.

Stopping the Leaks.—Generally, any ordinary leak is readily stopped by pine wedges. Sometimes a loose joint requires individual bands bolted around it. Bran or saw-dust is effective in stopping the small leaks which cannot be reached by the wedges. The good effect of the latter is likely to be destroyed by a rapid emptying of the pipe. If the water is drawn out faster than the air can enter through the air-valves, heavy vacuums are formed down long slopes, and the air forces its way in through the joints and between the staves. The result is that the pipe will frequently leak badly for some time after it is re-filled, although it may have been tight previously.

A full pipe and a steady pressure are highly desirable. This doubtless accounts to some extent for the extreme tightness of the wood pipe in the pumping main.

Grade Lines.—The hydraulic grade lines, shown on Plate LXX, were laid as best fitting the controlling elevations. The various diameters of pipe were determined by Darcy's general formula, with $C = 0.00033$ for wood and $= 0.00066$ for iron pipe, checking by Kutter's formula, with $n = 0.01$ for wood and $= 0.012$ for iron. These coefficients were taken as conservative and on the safe side, and such they proved to be. It was desired that the line should carry not less than 5 sec-ft. to Nogal and half as much beyond.

Velocities.—The pipe line from Bonito Creek to the Nogal Reservoir affords excellent conditions for velocity and capacity measurements, there being no distribution service from it. Beginning at the creek, it consists of 12 700 ft. of 10-in. wood pipe, with a hydraulic grade of 0.03338, followed by 48 000 ft. of 16-in. wood pipe, with a hydraulic grade of 0.0030625, ending on the south rim of the Nogal Reservoir. There is an open stand-pipe where the two pipes and grades join.

When this section of the line was laid, the last car of 16-in. pipe was late in arriving and, as it was desirable to get water into the reservoir as soon as possible, 500 ft. of 10-in. pipe were laid in the lower part of the 16-in. line, near the reservoir, as indicated on Fig. 2, which

shows the hydraulic grades and the pipe diameters of this section of the line.

When the first two velocity measurements, of March 10th and 31st, 1908, described below, were made (after the line had been put into service on February 20th, 1908), the 500 ft. of 10-in. pipe were still in the 16-in. line, and the hydraulic grade was defined by the solid line, *A B C D E*, Fig. 2.

When the third measurement, of May 12th, 1909, also described below, was made, the 10-in. pipe had been replaced by 16-in. pipe, and the hydraulic grade was defined by the solid line, *A B E*.

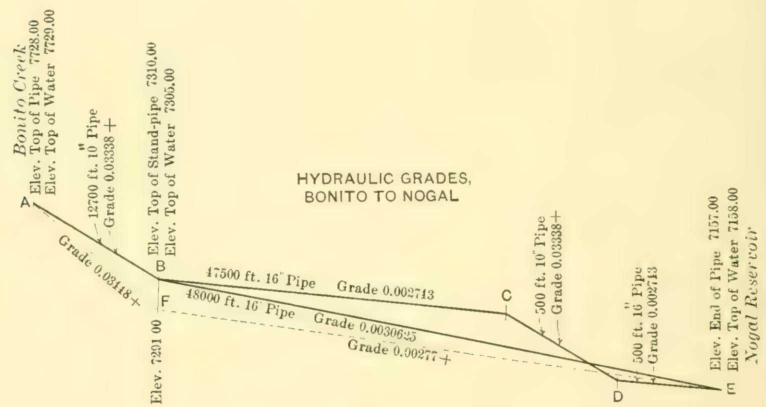


Fig. 2.

The dotted line, *A F E*, is the approximate theoretical position which the grade, *A B C D E*, should have assumed when the 500 ft. of 10-in. pipe were taken out of the 16-in. line. On the contrary, it took the position of the grade line, *A B E*.

During the interval between March, 1908, and May, 1909, the water came to overflow from the stand-pipe at *B*, when the line was running under full pressure, indicating an increase of capacity in the 10-in. pipe greater than a corresponding increase in the 16-in. The alignment of the 10-in. line, vertically and horizontally, is more regular and uniform than the 16-in. line. The latter has many abrupt curves and bends, vertically and horizontally. It crosses nine sharp ridges and dips under as many deep arroyos. This introduces a fixed element of frictional resistance which does not decrease with the increasing

smoothness of the interior surface of wood pipe, and probably accounts for the higher resistance of the 16-in. line.

From Fig. 2 it appears that, while the 10-in. line had an initial coefficient of roughness slightly greater than 0.009 and now equal to it, the 16-in. line had one equal at first but now slightly less than 0.01.

The line from Bonito Creek to Nogal Reservoir was to have a capacity of 5 sec-ft. Referring to the profile, it was determined that for the hydraulic grade of $33\frac{1}{3}$ ft. per 1 000 ft., a 10-in. pipe was necessary, and that a 16-in. pipe was required for the grade of 3 ft. per 1 000 ft.

Test No. 1.—On March 10th, 1908, a quantity of bran was poured into the upper end of the 10-in. pipe at A (Fig. 2), and the time of its appearance at the lower end of the 16-in. pipe at E was noted. The time was 3 hours and 50 min.

This gave:

Area of 10-in. pipe	=	0.5454 sq. ft.	
" " 16 " "	=	1.3960 " "	
Length " 10 " "	=	13 200 ft.	
" " 16 " "	=	47 500 "	
Time,	=	13 800 sec.	

Let x = velocity of flow in 16-in. pipe, in feet per second, then $2.56\ x$ = velocity of flow in 10-in. pipe, in feet per second.

From which:

$$\frac{13\ 200}{2.56\ x} + \frac{47\ 500}{x} = 13\ 800$$

$$x = 3.805$$

$$\text{and } 2.56x = 9.740$$

The discharge is:

For the 16-in. pipe, $1.396 \times 3.805 = 5.31$ cu. ft. per sec.; and, for the 10-in. pipe, $0.5454 \times 9.74 = 5.31$ cu. ft. per sec.

The question arose as to whether or not the particles of bran in the water traveled as fast as the water flowed. It was also desired to check by observation the relative velocities in the two pipes, as above deduced.

Test No. 2.—To determine these points, a second test was made, on March 31st, 1908, twenty days after the first one. In this test, green aniline, red potassium permanganate, and bran were used. An

observer was placed at the end of the 10-in. line at *B* (Fig. 2), and, by letting a small quantity of water run from a relief-valve there, he was able to note the time of the appearance of the colors and the bran.

The green was started in the upper end of the 10-in. pipe, at *A* (Fig. 2), at 8.30 A. M. It appeared at *B* in 22 min., and at *E* in 3 hours and 52 min.

The red was started at 8.45 A. M. It reached *B* in 21½ min., but it was so faded that the time of its appearance at *E* could not be noted exactly.

The bran was started at 9.00 A. M. It reached *B* in 22 min., and appeared at *E* in 3 hours and 51 min.

From the average of these figures, the velocities were:

In the 16-in. pipe,	3.792 ft. per sec.	
" " 10 " "	9.695 " " "	

and the discharges were:

In the 10-in. pipe,	5.287 cu. ft. per sec.
" " 16 " "	5.293 " " " "

The application of the equation for equalized relative velocities, as in the first test, gives:

Velocity in 16-in. pipe	= 9.705
" " 10 " "	= 3.791
Discharge of 16 " "	= 5.292
" " 10 " "	= 5.293

These last figures would check exactly, except for dropping figures in the fourth decimal place.

The results of these two tests, considering that 20 days elapsed between them, are in very close agreement, and establish the fact that bran is an accurate medium of measurement.

Test No. 3.—The 500 ft. of 10-in. pipe in the 16-in. line near the reservoir (Fig. 2) were replaced by 16-in. pipe in the summer of 1908.

On May 12th, 1909, green aniline was started through the pipe at *A* at 11.00 A. M., 11.30 A. M., and 12.00 M. In each case it appeared at *E* in 3 hours and 31 min. This time is 20 min. less than that observed in the tests of the previous year, and is due to the removal of the 10-in. pipe from the 16-in. line and to the increasing smoothness of the interior surface of the pipe.

The relative velocities and discharges under the third test, using the nomenclature of the first and correcting the lengths of pipe on account of the removal of the 10-in. pipe near the reservoir, are:

$$\frac{48\,000}{x} + \frac{12\,700}{2.56\,x} = 12\,660$$

$$x = 4.183$$

$$\text{and } 2.56\,x = 10.708$$

and the discharges are:

From the 10-in. pipe = 5.840 cu. ft. per sec.
" " 16 " " = 5.839 " " " "

Coefficients.—On May 12th, 1909, the 10-in. line was working on a grade of 0.03338, and, with $n = 0.009$, C should have been 131. It was actually 138, making $n = 0.00866$. The 16-in. line was working on a grade of 0.0030625, and, with $n = 0.009$, C should have been 145. It was actually 141, making $n = 0.0092$.

Referring to the estimated hydraulic grade between Coyote and Corona (Plate LXX), the coefficients, 0.01 and 0.012, were used for wood and iron, respectively, on which basis, the maximum pressure at Coyote was expected to be 304 lb. and, at Luna, 310 lb. per sq. in. The actual maximum at Coyote, with pumps at full normal speed, was 270 lb., and, at Luna, 278 lb., indicating that the values of the coefficients taken were too high. This checks with the tests between Bonito and Nogal.

Of course, the iron pipe will increase in roughness, and, in time the pumping pressure will approach the calculated amount. The interior of the iron pipe now has a smooth coat of asphalt.

Pipe Breakage.—The breakage or damage to the wood pipe in shipment occurred on the ends, the tenons being most exposed to injury from shifting in the cars. The damage due to the shipment and handling of the Elmira pipe was 1% and one-half as much for the Bay City pipe. Less than 6 pieces out of 100 000 laid, have had to be removed from the trench.

The iron pipe came from Chattanooga, and was badly handled in transit. Much of it was transferred en route, and 6% was broken when received. The breaks were generally cracks of the spigot end. Of this broken pipe, practically all was cut and laid. The average cut was about 16 in. from the spigot end of 533 pieces. This cut pipe has caused no trouble in the trench.

At least 27 pieces of cracked pipe got past the field inspectors and into the trench. This cracked pipe began blowing out at a pressure of 50 lb., and continued until the full normal pumping pressure was reached, when the breaks suddenly ceased. These pipes were broken out at the rate of 1 or 2 per day, with an occasional day between breaks. A 24-hour work-train service was maintained. The pipe gang soon became skilled, and could put in a new section of pipe in from 4 to 6 hours. Each break generally caused an interruption of about 6 hours to the pumps on the section where it occurred. The best record was 3 hours and 50 min. from the stopping to the starting of the pumps. This strenuous life lasted 30 days. Most of these breaks were in or near the middle of the pipe. Evidently, the field inspectors were not expecting cracks in that locality. An inspection usually indicated that the pipe had been struck by the bell of another one in the vicinity of the break.

All pipes were lifted from the car carefully and laid down at the trench along the track in a single movement by a logging crane, and were not broken in such handling.

Three breaks only have been reported as due to defective metal or casting. No break of a sound shell of full thickness has been found.

Trenching.—Deep frosts are unknown in this section. The pipe was laid so that the top was about 1 ft. below the surface of the ground. The trenching was a simple matter. Part of the work between Bonito and the railway on the Carrizozo plain was done by Buckeye ditchers. All other ditching was done by a railroad plow followed by pick and shovel, or by the last two tools only. The ditcher could open 2 000 ft. of trench per day, but averaged about 500. The plow and 35 men could open 3 500 ft. A chain about 6 ft. long separated the end of the plow beam and the double tree. In this way the trench was plowed to the bottom. Two mules, two men, and a scraper could back-fill 3 500 ft. per day.

Pipe Laying.—Between Bonito and the railway, one gang of ten men could lay 4 000 ft. of 12-in. pipe per day. The average was much less, owing to a variety of causes. At the end, the railway company added to the contractor's force, and laid the last 10 miles of pipe in 7 days, there being a half dozen separate gangs at work.

Along the railway, the day's record on wood pipe was 4 000 ft. of 11-in., 6 200 ft. of 7½-in. and 8 345 ft. of 3½-in. pipe laid by a gang

of eight men after the pipe was distributed along the trench. These eight men, of whom five were Americans, laid 76 miles of pipe, and became expert. Their operation was like the working of a clock.

On the 12-in. iron pipe, the regular day's work was 96 joints, or 1 152 ft. of pipe laid and caulked. The record was 1 644 ft. Two gangs laid 101 300 lin. ft. in 60 days. Such a gang consisted of 1 foreman, 1 inspector, 8 caulkers, 4 yarners, 1 melter, 1 pourer, 1 helper, and 10 men putting pipe into the trench.

Cost Data.—The pipe from Bonito to the railway was laid by contract. The price was 18 cents per lin. ft. laid and back-filled from the railway to the Nogal Reservoir, and 28 cents from Nogal to Bonito. In addition, 50 cents per ton per mile was paid for hauling pipe, and extra compensation for setting valves. From Coyote, east along the railway, the work was done by the railway company under the writer's direction.

The total cost of laying 384 300 ft. of wood pipe, from 11 to 3½ in. in diameter, was $18 156.77, or 4.72 cents per ft., divided as follows:

Ditching	$0.0249
Laying	0.0113
Back-filling	0.0110
Total	$0.0472

This includes unloading from the cars. Train service cost ⅓ cent per ft. additional.

The pipe gang, including back-filling, consisted of 1 foreman, at $100 per month, one assistant foreman at $75, and about 30 Mexicans at $1 per day. The rates were the same in the ditching gang. The plow team cost $6 per day.

Including all general expense, the cost does not exceed 6 cents per lin. ft.

The cost of laying 101 300 ft. of 12-in. cast-iron pipe was $23 826.67, or 23.5 cents per ft., divided as follows:

Ditching	$0.0249
Laying	0.1180
Back-filling	0.0110
Lead	0.0790
Oakum	0.0014
Total	$0.2343

This includes train service and unloading pipe, but nothing for tools. The foreman and inspector received $100 per month, the caulkers, $3; pourer, $3; melter, $2.50; 2 pipe-men, $2, and laborers, $1 per day. Professional caulkers wanted $5 per day. Carpenters, blacksmiths, and boiler-makers made good caulkers; their work is standing perfectly under a 275-lb. service.

The cost of the pumping plants complete per horse-power is as follows:

Pumps	$79.00
Boilers	18.70
Building	41.70
Total	$139.40 per h.p.

The approximate cost per million gallons of storage capacity is as follows:

Nogal	Storage	Reservoir	$103.00
Carrizozo	Service	"	3 040.00
Coyote	"	"	2 880.00
Luna	"	"	3 480.00
Corona	"	"	2 720.00

To cover general expense, 3% should be added to all the costs above given. The costs per foot of pipe-laying include the setting of all specials, valves, and stand-pipes. The difference of cost in laying 11-in. and 3½-in. wood pipe is not nearly as great as the difference in diameter or the total quantity laid on record days. While the record is 4 000 ft. and 8 345 ft., the 76 miles of pipe of all diameters were laid in a total time, including all delays, of 223 days, or an average of only 1 723 ft. per day. The cost of the 11-in. pipe is covered by 7 cents per ft. The pipe was laid by a single gang as fast as it was received from the factory.

The reduction from 7 to 3½ in. at Mile 230 (Plate LXX) is on account of delivering water to the Santa Fé's new transcontinental low-grade line which crosses the El Paso and Southwestern Railway at Vaughn, and has a division point there. On its adjacent divisions, the Santa Fé had the same trouble with local waters which compelled the El Paso and Southwestern to find a better supply. The Bonito water is conducted to and used at points 160 miles from its origin on Bonito Creek.

AMERICAN SOCIETY OF CIVIL ENGINEERS
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PAPERS AND DISCUSSIONS

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PRECARIOUS EXPEDIENTS IN ENGINEERING PRACTICE.

Discussion.*

By Messrs. W. W. Crosby, J. S. Branne, Andrews Allen, Guy B. Waite, and J. H. Gandolfo.

W. W. Crosby, M. Am. Soc. C. E. (by letter).—The writer has read Mr. Hawkesworth's paper with much interest and sympathy, and has been especially struck with the paragraph concerning the duties of an "Inspector." The author has "put his finger on the button" of a source of great conflict between contractors and owners, or referees. As a rule, contractors, or their working representatives, are older, and much more experienced in dealings with others, than the best of inspectors. When an inspector becomes the equal of working superintendents along these lines, he seldom remains an inspector long. If, therefore, an inspector, incapable by lack of experience and maturity of judgment, is given authority and placed in a position to bind or hamper the decisions of the referee named in the contract, the result may be unfortunate or disastrous. Unscrupulous contractors undoubtedly exist, who do not fail to take advantage of such a situation. The writer regrets that so many contractors seem to regard the obligations placed on them by their contracts as not mandatory and not matters to be lived up to in spirit because of the agreement that they shall be fully carried out. Many contractors, on the contrary, seem to regard the specifications under which they agree to do work as merely statements of the things which the owner or referee will try to accomplish; that it is the duty of the referee to en- Mr. Crosby.

*This discussion (of the paper by John Hawkesworth, Assoc. M. Am. Soc. C. E., printed in *Proceedings* for January, 1910, and presented at the meeting of February 16th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

Mr. Crosby.

force them if he can; and the privilege of the contractor to evade as many of them and as far as he wishes. To place a young, perhaps inexperienced, party in a position to decide the many points that may be raised by an experienced superintendent or foreman is almost sure to prevent the owner, who pays for work done according to the specifications, from getting what he pays for, to which he is entitled, and which the moral obligation on the contractor alone should compel the latter to deliver. The writer can recall numerous instances where, as the inspector's authority was not clearly limited in the contract, the contractor claimed that the referee and owner were estopped from finally securing the kind of work the owner was clearly entitled to and the contractor had agreed to give him, and had named his price for giving him, because the inspector had "accepted" the inferior work or had failed to "condemn" it.

The writer believes it is far fairer and better in every way, including all considerations of justice to the contractor and to other bidders, to provide, as suggested by the author, that an inspector shall simply report the facts, and that the decisions shall be left to the owner or the experienced referee specified. Some greater delay may occur in securing final decisions under the latter method, but the decisions will undoubtedly be more just on the average, and, except in those cases where questions are raised for the purpose of evasion or for making difficulty, when delay in the decision may be justified, they will be more in accord with the spirit of the contract. In the work of the writer, the following clauses are contained in the specifications:

"An Inspector employed by the Commission may be stationed on the work under the contract by the Chief Engineer to report whenever the Contractor appears to fail in carrying out the terms of the contract or specifications in any particular. Any advice which an Inspector may give the Contractor shall in no wise be construed as binding the Chief Engineer in any way nor releasing the Contractor from the proper fulfillment of the terms of the contract as determined by the Chief Engineer. An Inspector shall perform such other duties as the Engineer may indicate. The Inspector shall in no case act as a foreman for the Contractor nor interfere with the management of the work by the latter.

"The amount of work done by the Contractor shall be measured by the Engineer. In that character of work which would require for its measurement a detailed tally of the materials as delivered on the work, a tally shall be kept by the Inspector who shall at the end of each day compare his tally with that of the Contractor or foreman in charge. The Inspector shall send daily his tally, with the Contractor's or his foreman's signature, to the Engineer. Should there be a dispute between the Inspector and the Contractor as to the amounts in any particular instance, the Contractor must immediately send his account to the Engineer. If no tally of materials delivered, other than that of the Inspector, is received by the Engineer within five

days after the receipt of the Inspector's tally, the Engineer's estimate may be based upon the reports as made by the Inspector, whether or not these reports are signed by the Contractor or his foreman, and they may be the basis of payment to the Contractor. Whenever any differences exist, the decision of the Engineer shall be final and binding upon both of the parties to the contract." Mr. Crosby.

Complaints of delay on account of the lack of authority of the inspector, especially where the latter has been young or inexperienced, have been received from contractors who, it was evident to the chief engineer from the general conduct of their work and personal attitude, were ignorant, incompetent, or at least not trying fully to live up to their moral obligations; but serious complaints from efficient and conscientious contractors have not reached the writer. On the contrary, the methods of his office seem to be approved by those whose approval is valuable.

J. S. Branne, Asso. M. Am. Soc. C. E. (by letter).—This paper is a plea for the maintenance of a high professional standard among engineers, not only as to the product turned out, but also as to the manner in which the materials are collected for a design of some magnitude and having a variety of detail in several distinct branches of engineering, a thorough knowledge of all the subjects to be considered being rarely available in any one office. The ends desired by all engineers are: To carry out work in such a way that the result is excellent, not only because it is economical and safe and gives a good return for the money invested by the owner, but also because the means used at all times to achieve such ends are just to all concerned, both in planning and building the work, by having clear drawings, specifications which are concise and without redundancy, an equal opportunity for all bidders, and favoritism to none. This paper, which calls attention to abuses, more or less apparent, and suggests means for opposing them, is very timely, and will benefit the Profession, and therefore the measures it advocates should be supported. Mr. Branne.

There is hardly a piece of work the perfect execution of which does not involve many specialties, from two or three to perhaps a dozen. This is necessarily so, as the tremendous strides with which the engineering arts and sciences have advanced during the last 25 years have enabled business men to place on the market an almost endless variety of appliances and materials, all produced by special knowledge and careful study of economy and utility. What man, then, after attending to his own special work, that is, work in which he is pre-eminently trained, say as a sanitary, electrical, hydraulic, structural, or railroad engineer, not to mention all the other specialties, and, as a rule, finding that it takes all his time to keep abreast with the developments in his own line, can also pass on all the specialties in other lines, admitting that he has good judgment and is a hard worker? Clearly, he can

Mr. Branne. not, but must call to his assistance men who are specially trained in other lines which they have made their life study. The difficulty then becomes apparent: He has not enough money allotted to pay for all this special knowledge, and, unless he has plenty of time to study the matter up himself, he has to accept free advice from the men who sell these various articles. Free advice, however, is not free to the owner, as the laws of compensation hold good here as elsewhere, and while there can be no proper objection because the owner pays for the advice, yet it has the disadvantage that it stifles fair competition by giving the favored free adviser special privileges in a thorough knowledge of the plans or by introducing special articles, of which there may be several varieties, but his own is specified. Clearly, it is to the interest of the owner to pay a specialist for his unbiased advice; for the owner must pay for advice, and why not pay a man whose sole object is the safety and economy of the work on which he is consulted, and who has no special device of his own to sell?

The engineer's object is to carry out works for the welfare and convenience of man in a safe and economical way; in other words, the engineer makes improvements possible by his knowledge of the applied sciences, and it is his sole duty to plan his special work in such a way that attention is paid to locality, permanence of work, future requirements, present resources, and other matters. The "designer"—as Mr. Hawkesworth terms the engineer or architect-in-chief—will then give a fair chance to all bidders, by having the features with which he is acquainted only in a general way planned by an engineer specialist; for the specialist, without confining himself to one or two things, can indicate clearly to all bidders what is wanted, and being a judge of the excellences of all, he gives the freest scope to fair competition. It is granted that the manufacturers and general contractors have just as able engineers at their service; but, at the same time, the manufacturers are bound to look after their own "future requirements, resources, etc."

Mr. Hawkesworth has suggested many ways by which the interests of the Profession may be safeguarded and mistakes in the conduct of business avoided, thus making for the maintenance of high standards. Little can be added in regard to the methods advocated, but it seems pertinent to say that, to carry on work along such lines, giving the best in everything, can be possible only when owners understand the benefits accruing to them by paying enough for professional services so that skill can be employed. It appears, therefore, to be the duty of all engineers to try and get work, not simply by stating how cheaply their services can be had, but by showing how cheaply work can be carried out when they are paid well enough to give attention to all details; this would be a sort of campaign of education, bound to be beneficial both to engineers and owners.

An engineer who has the good fortune to carry out his work on the highest professional lines will gain still more good fortune as the years roll by, if he manages to be alive when his well-earned reputation becomes firmly established, as it is bound to become, sooner or later; for painstaking care in all details, however small, will enlarge his knowledge and ripen his judgment, and, although no man can plan work so as to be free from mishaps of some kind or other, it is his duty to take all precautions. Probably the best way for engineers to get in line for a high class of work is to learn all they possibly can about their specialty, and enough about other lines to pick out the men who can assist them most efficiently, and let them do their end of the work. Even if engineers are, financially, immediate losers, due to insufficient funds, the results of such co-operation must produce the best returns, and will eventually gain for an engineer the reputation of being reliable and a man who takes enough pride in his work to allow no part of it to be ill performed. Mr. Branne.

ANDREWS ALLEN, M. AM. SOC. C. E. (by letter).—The thanks of the Engineering Profession are certainly due Mr. Hawkesworth for his timely paper. There is far too little attention paid to the ethical and moral standards of the Profession in papers and discussions published by the Society, as they usually deal with physical facts and methods of work, things done and the mechanical tools for doing them, forgetting the human elements which are the most important of all. Mr. Allen.

The engineer, in the different lines in which he works, sustains important relations, and is vested with great responsibilities which involve far more than technical skill. As engineer in charge, or as "designer," he represents the business interest of the owner, and at the same time is given supreme power as arbitrator between the owner and the contractor. As contractor, or as engineer for the contractor, he has to conduct difficult negotiations with the owner or his engineer, see that the work is done right and in accordance with the requirements, and get a profit out of the job. Each engineer, and, to a smaller extent, each subordinate, has an organization to maintain, the efficiency of which depends largely on the loyalty, confidence, and co-operation he is able to secure among his men. Success depends more on the personality, vigor, fairness, and honesty of the engineer than anything else, and still technical societies are doing almost nothing to direct or encourage growth along these lines; and engineering business methods are doing quite the reverse. If an engineer does not happen to be born with these qualities fully developed, he has a hard time getting any assistance in developing them. Nearly all educational methods are based on the idea that good morals cannot be taught in schools, and the young man is expected to get this part of his education at church, where he is very apt to get only the husks

Mr. Allen. of ethics or morality, with no ideas as to applying them, or in the home, where the faults of the present generation are perpetuated. The natural result is that most young men get no moral education at all, and are thrown into business conditions which they do not fully understand, and with no real conception of right and wrong. If things look a little queer to them, they just excuse them under the old motto that "Business is business," which, if it means anything, means that any methods are right which bring money into your pocket or the pocket of your employer. If men are not hopelessly corrupted at the start, they drift around without any adequate moral standards—unless they are so fortunate as to get their moorings somewhere—and build a system of ethics which satisfies their requirements. It is no wonder, therefore, that many of them go wrong professionally, not engaging in acts which are criminal under the law, but acts, such as those mentioned by the author, which simply show the lack of a proper ethical standard or the strength to live by it.

The author has mentioned only a few of the things which are being done every day, both by "designers" and contractors. A "designer" or an owner will often get a detailed plan of some part of the work from a contractor, cut off the name, and submit it to other contractors for bids. A contractor will frequently make use of his opportunities, when called into consultation by the "designer," to "load up" the work so that he is able to underbid all competitors, and then, as the author states, cleverly "unload" again by offsetting one change against another, make a good profit, and perhaps do a most excellent piece of work where another contractor might have lost money.

These are rather flagrant but none the less common examples. Going a step farther: How many engineers, and how many contractors, do their work as though it were their own and they were doing it for themselves? How often one hears the question: "Who pays for this? Is it lump sum or unit price? If we have to pay for it, we'll leave it out; if the other fellow pays for it, we'll put it in." How many times does the "designer" refuse to allow or to make a desirable change in his plans for fear the contractor will make a little more money. How often does the contractor fail to call attention to changes or modifications in methods or plans, which might benefit the owner or the work, because his own interest might suffer thereby. So it is all the way down the line, until one cannot help wondering what is really the matter. The author suggests certain remedies, many of which are excellent and all of which show the right spirit, but here one runs up against an economic law. The owner is paying the bills and does not see why he should pay for so many kinds of expert advice when so much of the best expert talent is already in the service of the contractors or manufacturers, and necessarily so,

because their very life as manufacturers or contractors depends on such talent. A great deal of special consultation usually means a duplication of effort and expense, and an economic loss. If the consulting specialist should ever take full control of all departments of designing, the writer believes that there would be a swift deterioration in productive efficiency and ultimately in engineering merit. The place for the expert specialist is near his tools. Mr. Allen.

The writer is afraid, therefore, that the author's actual remedies are directed more toward the symptoms than the real disease. But what is the real disease? Partly commercialism, the wish to get something for nothing, but principally, as it seems to the writer, the fact that the immediate interests of all the various parties to contract work—owner, "designer," contractor, and sub-contractor—are necessarily and absolutely at variance.

The immediate self-interest of the owner, before the work is let, is to obtain the lowest possible prices by every means in his power, and after the work is let, to get as much as he can out of the contractor. The immediate self-interest of the "designer" is frequently to make the work cost as much as possible, and to slight it all he can. The immediate self-interest of the contractor before the work is let, is to underbid his competitors, and after the award, to get out as best he can. It is a state of war in which each party has many weapons, and neither can be blamed very much for using them. It is not much worse for the contractors to pool a job than for the owner or "designer" to play one bidder against another. Both are stratagems of war, and the only marvel is that things are no worse. An honest contractor and a fair and broad-minded engineer are both entitled to the very highest credit, for they can only be developed, under the present system, by forgetting immediate self-interest and looking forward to the ultimate reward of true honesty.

So we start with no adequate moral training, practically nothing is done in the professional societies, and engineering business methods are such as to put a premium on self-seeking cleverness, and not on honesty and real manhood.

The writer realizes that business conditions are matters of gradual development. Engineers could not change their methods suddenly if they would, or if they saw clearly the way to change them, but they can take a step once in a while in the direction of better conditions, and so gradually improve them. It is the writer's conviction that conditions never can be good until the interests of all parties connected with engineering work, from owner and "designer" to contractor, are all directed to the same end, and that end, the excellence and true economy of the work. The thing that blocks the path of improvement is the method of contracting for engineering work by price competition.

Mr. Allen. Anyone familiar with contract work knows that a tremendous price is paid, in shoddy work, inefficiency, and moral diseases, for competition, and yet we are told that it is a sacred thing, and that absolute freedom of competition is necessary to progress. The writer freely confesses that he is a heretic. In the first place there never has been, and never will be, free and perfect competition. In the second place, it has already become necessary to substitute "regulation" for competition among the railroads, and it soon will be necessary to do the same thing with the trusts. It is perfectly true that, in the past, much progress has come through competition. In the same way, much progress has come through savage warfare, but it does not follow that price competition is necessary or beneficial to-day any more than it follows that we should throw away our government regulation, arbitrations, and courts of law, and go back to settling our disputes with our fists or our battle-axes.

Of course, something will have to take its place. Most men still need a great incentive to put forth their best efforts; but why not devise some method of securing a "competition of excellence," instead of price? And such a method can be devised. The "fee basis," modified perhaps so that profits below or losses above the estimated cost are shared in certain proportions, seems to offer a hint of the true method. The contractor is assured of a reasonable profit, and is also benefited by economy of operation. The interests of all parties are as near to those of the owner as it is possible to make them. The owner gets the benefit of the contractor's experience and equipment. The contractor has to depend on his reputation for honesty and efficient work, instead of a low bid, for getting his contracts, and, still more important, all parties can co-operate, after the contract is let, to obtain the best results for the benefit of all. Anyone who has done work fairly and honestly under this method will bear testimony to the way in which the difficulties, misunderstandings, and "dangerous expedients" vanish like mist before the sun. The expert or engineer of the contractor has a recognized standing at court. The "designer" is free to devote himself to the larger elements and relations of the work, and to avail himself of the full value of the expert services of the contractor or manufacturer, and the contractors will be selected because they are the best in their lines, and not because one happens to leave out enough in his estimate to make him a low bidder.

Of course, this is Utopian. It will require great changes in business methods, and the cutting away of much dead timber. It will require higher moral standards, but it will breed them in turn, and the writer will be satisfied if he has succeeded only in calling attention to the problem, in the hope that our thoughts and efforts may help future generations to outgrow some of our present trouble,

and build wisely and well, not only their engineering and architectural works, but the character and manhood of the profession and of the race. Mr. Allen.

Guy B. Waite, M. Am. Soc. C. E. (by letter).—On first glancing at this paper the writer thought that it was one more of the numerous censures for the contractor and praise for the zealous efforts of the designer to remedy the evils existing in the business of the designer, owner, and contractor, but a careful reading has satisfied him that there is one designer who is able to give an unbiased opinion of the conditions existing, in his particular sphere, between designer, owner, and contractor. Mr. Waite.

The author is undoubtedly revealing truths derived from personal experience. Evidently, he does not belong to that class of designers who assign all the evils existing in the contracting business to the contractor, and give all the credit for efforts to remedy the same to the engineer.

Although the author has covered the particular field of action which he has in mind with credit and satisfaction to both his profession and the contractor, yet the writer feels that it is not entirely out of place to refer to other actions between designers, owners, and contractors, not mentioned in the paper. He refers more particularly to actions between designers and contractors which, ethically, he would term "dishonest honesty."

Competent designers know that all valuable experiences, as to the costs of any new design, etc., are luxuries which are expensive in time and money. If such designers are wise, they save the necessary time and money for these experiences by taking into their confidence some honest and competent contractor. Seldom does the contractor hesitate to drop all and give his best advice to the designer, even when his running expenses are such that time is money to him.

There are many contractors giving such advice, who, in no way, would mislead a designer for any personal interests, and would not wish to place any designer in a position to feel that he was under obligations. All that such a contractor would expect would be an equal chance, on the same plane as other contractors, when the time came to take estimates and award contracts. The interchange of knowledge between the honest designer and the honest contractor would seem to warrant a mutual condition of confidence, whereby the contractor deserves the same consideration as given to other parties who have not assisted so freely in making the engineer's or the architect's plans practical. However, a peculiar condition sometimes exists among designers and contractors, whereby, after the contractor, at the suggestion of the designer, has done all that was possible, the latter seems to think it his professional duty either to forget him entirely or place

Mr. Waite. him at a disadvantage. The feeling on the part of the designer seems to be that some one may suspect him of being too friendly with the contractor. If such a contractor should be so unfortunate as to beat all comers, however much they forgot to include, and obtain the contract, then the appreciating designer becomes worried, and studies how he can prove to the owner that he is working solely for him.

The designer at every turn stands on the blanket clauses in his contract, which state that "everything necessary, whether shown or specified, shall be furnished without extra cost." This is intended to cover his many oversights.

When there is any doubt as to the plans and specifications covering extra work, and the owner is convinced that he should be indebted to the contractor, then the designer intervenes, and advises the owner that he can just as well have it for nothing. If one kind of cement or one form of patented device will serve as well as another, and the contractor is being held up for a large bonus, the designer asserts his authority, and demands that there shall be no variation. He shows the owner from time to time how it pays him to have an "honest designer," and how much he has obtained from the contractor for nothing. It never occurs to him that the cost of the next work he designs will be increased by every one who knows him.

Another designer, whose character differs slightly from that of the foregoing, is the one who feels himself to be so weak that he imagines it will make him appear strong to persecute his best friends and grant favors to his enemies. In this way he seems to think he can establish the fact that he is very fair.

Characters of these types are quite common among "highly educated" professional designers and those who want people to think they are highly educated. The writer mentions these classes, and places them in the list of "dishonest honest" designers, not from personal impressions, but because they seem to stand in their own light, and should be considered when making up a code of ethics between the designer, the owner, and the contractor.

Mr. Gandolfo. J. H. Gandolfo, Assoc. M. Am. Soc. C. E. (by letter).—It has often been said of engineers that they are so interested in the technicalities of their profession, and so absorbed by the requirements of the immediate work in hand, that they have neither the time nor the inclination to consider the broader ideas of life, or those general questions that link the Profession to the rest of mankind. This fact is typically exemplified in the opening paragraph of this paper, wherein the author thinks it necessary practically to apologize for presenting a non-technical paper. The Society should welcome such contributions to its literature, and it would be to the advantage of the Profession, and would broaden the understanding between it and the general public, if more papers of this class were presented.

Mr. Hawkesworth has done well to call attention to certain questionable practices by some engineers. Of course, there is a natural tendency to keep "mum" on such a subject, but the time has come when it is the duty, not only of the engineer, but of everyone, to expose "graft" in any form or shape. Unfortunately, we are living in an age when, if a man rides on a transferred transfer ticket, he is treated as a criminal. On the other hand, if a man issues to the public so-called "securities" that represent nothing, and, further, makes way with the entire funds of banks by borrowing on such "securities," he is applauded as a financier. Perhaps the majority of people do not realize to what an extent "graft" (which is only another word for "dishonesty") has developed in some classes of engineering enterprises, and the following occurrences, which have been brought to the writer's attention, may be of interest. In this discussion the term, "designer," will be used in the same sense as in the paper. Mr. Gandolfo.

On a certain job involving the use of some 4 800 tons of structural steel, the contract was let to a steel contractor without calling for bids and with the understanding that the contractor was to prepare the general and detailed plans, which work was to be supervised, and the drawings finally checked and approved, by the "designer." The reason for this method of procedure developed later, when it was found that several directors of the purchaser's company were also on the board of the steel contractor. The "designer's" chief assistant engineer, a young man, warned him, before the contract was let, that, as it was to be on a pound-price basis, fraud was likely to creep in, as there might be an unnecessary increase in the weight of the structure. He was told by the "designer," a man much older and more experienced than himself, that such a concern as this contractor would not stoop to any such practices.

As the work progressed, the "designer's" assistant repeatedly had occasion to call the attention of his superior to places in the design where totally unnecessary material was being introduced. The "designer," influenced perhaps by the knowledge of the similarity in directorship, did not take any radical action, in spite of several stormy interviews with the contractor's engineers. The final result was that this steelwork cost, in round numbers, $50 000 more than it should.

Another incident, which concerns an architect, shows, by inference, what may be done. Three firms, one of which will be called the "favored contractor," were asked to bid on a certain job. When the bids first came in, that of the "favored contractor" was found to be the highest. All the bids were rejected, some minor alterations in the plans were made, and new bids were called for. Again the "favored contractor's" bid was the highest. The same process was repeated, and, on the third attempt, the bid of the "favored contractor" was just $50 less than that of the next lowest bidder. Of course, no one can

Mr. Gandolfo. say that there was collusion between the "designer" and the contractor, short of a direct confession from one or the other, but the facts as they are known are submitted for consideration.

One more illustration, concerning a general contractor: In this case, also, there were said to be some of the same directors on the boards of the purchaser and the contractor, and it was also said that the same banking house was financing both enterprises, but of this there is no proof. The contractor in question was brought to the attention of the "designer" after bids had been received and the contract was about to be closed. Needless to say, this contractor obtained the job, by what means is not known, so he will be given the benefit of the doubt, and it will be taken for granted that he was honestly the lowest bidder.

As the work progressed, it was found that inferior materials and inferior workmanship were being put into the job. The inspectors made report after report to this effect, the division engineer, who had charge of this work, stormed and protested, and the "designer's" assistant wrote report after report to his chief, setting forth in detail wherein the work was not up to the plans or specifications. In the meantime the contractor went calmly on the "even tenor of his way," secure in the knowledge that he held "the cold end of the poker"; and so it proved, for in spite of united action on the part of all the subordinate engineers connected with this work, nothing was ever done. And further, as the time drew near for the final settlement of this contract, every subordinate inspector or engineer, both on the purchaser's side and on the contractor's side, who had been on the job from the first, and who knew where details had been omitted and where credits were due, was dismissed on one pretext or another, so that when the work was finally finished, not one of the original engineers, except the "designer," was on the job. Shortly after, and before the final payment, even the "designer" thought it expedient to take an extended trip to Europe, leaving the matter of settlement in the hands of those totally ignorant of the details and progress of the work.

In closing, the writer may state that perhaps it has been his fate to have more of these matters brought to his attention than falls to the lot of most engineers, and he hopes that this is so. Tennyson has said:

"There lie two ways to every end,
A better and a worse."

The writer trusts that, as time goes on, it will be found that engineers have always, without exception, followed the first of these two roads.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

EXPANSION OF PIPES.

Discussion.*

By William D. Ennis, Esq.

William D. Ennis, Esq.† (by letter).—Mr. Taggart has rendered a real service in reducing to quantitative form the various assumptions which engineers have had to make in designing pipe lines in order to provide for expansion. There is no question as to the benefit, in some cases, of merely treating a long transmission line as suggested in Fig. 27; but this seems to be a clumsy expedient at best, to be resorted to only as a means of getting around a difficulty quickly and cheaply. The use of cold strain in erection has been thoroughly tried out by the fitters, and always with success; it cannot be too strongly insisted on that all piping should be erected in this way. Mr. Ennis.

The writer does not follow Mr. Taggart's apparent condemnation of the bend as an expedient for expansion resistance, having supposed that its shape, ordinarily at least, gives it a susceptibility to flexure greater than that of the straight pipe with elbows. Certainly there is less likelihood of leakage at the end joints when bends are used. If this is not due to greater flexibility, on what grounds is it to be explained?

Both cold straining and expansion strains have an important relation to flange pressure. The ordinary pipe flange, with a continuous face, has a contact pressure due to bolting only slightly in excess of that necessary to hold it against high strain pressures. Unless the question of anchorage is carefully worked out, cases sometimes arise in which the cold strain or the expansion may compel a flange to leak.

* This discussion (of the paper by Ralph C. Taggart, Assoc. M. Am. Soc. C. E., printed in *Proceedings* for February, 1910, and not presented at any meeting), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Professor of Mechanical Engineering, Polytechnic Institute of Brooklyn.

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PAPERS AND DISCUSSIONS

THE EFFECT OF ALKALI ON CONCRETE.
Discussion.*

By Messrs. R. A. Hart, Rudolph Hering, Philo H. Bates, Thomas H. Means, F. E. Robertson, George F. Morse, and Richard H. Gaines.

Mr. Hart. R. A. Hart, Esq.† (by letter).—The action of alkaline waters on Portland cement was brought to the writer's attention in August, 1908, by the discovery of the deterioration of some cement drain tile which had been placed in a field, in Sevier County, Utah, during February of that year.

The tile were well made and well seasoned, and in good condition when placed in the ground. Utah Portland cement was used, one part of cement being gauged with five parts of an aggregate of sand and small gravel. The tile were stored in a shed and kept damp for two months previous to laying.

After five months, the tile were in an advanced stage of decomposition, and it was possible to scrape a hole through their walls with an ordinary pocket knife; pieces of the tile could be crumbled in the hands. The material was saturated, and had the appearance and consistency of fresh lime mortar, except on the very surface, where there was a greater percentage of cement.

The water flowing from the drain was highly impregnated with the salts of various alkalies, and this fact seemed to offer a possible explanation of the deterioration. As very little information was to be had, at that time, concerning the destructive influence of alkalies, it

* This discussion (of the paper by George Gray Anderson, M. Am. Soc. C. E., printed in *Proceedings* for December, 1909, and presented at the meeting of February 16th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Asst. Drainage Engr., Bureau of Drainage Investigations, U. S. Dept. of Agriculture.

was decided to make some laboratory experiments to determine which of the alkaline salts was doing the damage, and, if possible, to devise methods of preventing it. The chief salts of interest in drainage investigations are the chlorides, carbonates, and sulphates of sodium, and it was with solutions of these that the experiments were made. Mr. Hart.

The experiments were conducted in the Mechanical Laboratory of the University of Utah, and the methods proposed by the Special Committee on Uniform Tests of Cement, of the American Society of Civil Engineers, were generally used. All the equipment was of standard type, and the best materials were used (standard Ottawa sand in the sand briquette tests).

Several series of tests were run, and each final result shows the average obtained from five separate experiments.

The first series was a determination of the setting periods of pats of neat cement gauged with solutions of the three sodium salts, chloride, carbonate, and sulphate, each in four different strengths, 0.1%, 1.0%, 5.0%, and 10.0%, and with tap-water.

Test I (shown in Table 1) shows the results of this series. Very little effect in the period of set is made by the addition of sodium chloride, except in the case of the 10.0% solution. The results, in the case of sodium carbonate, however, are very marked, both the initial and final sets being delayed in those pats gauged with a 0.1% solution, while the stronger solutions cause a remarkable expedition. Special attention is called to the period of initial set of Pat 9, which was 6 min., as against 3 hours and 39 min. for the water-gauged pat. Careful examination showed that the set was genuine, and not merely a crystallized surface film. This rapid set, instead of resulting in a weakening of the cement, has the contrary effect, to a remarkable degree.

The second series is a determination of the tensional strength of neat-cement briquettes, gauged with solutions of chloride, carbonate, and sulphate of sodium, in strengths of 0.1%, 1.0%, 5.0%, and 10.0%, and with water, and then stored in water for various periods of time. The results are shown in Table 1.

Test II shows that at the end of 24 hours the presence of chloride and carbonate causes an increase in the tensional strength, which is not true of the sulphate, except in the case of the 10.0% solution.

In Tests III, IV, and V, the changes show less definition, but it seems, in general, that the water-gauged briquettes are a little stronger than those gauged with alkaline solutions, except in the case of the stronger sulphate mixtures. In one or two instances, the 1.0% solutions of chloride and carbonate give higher results.

In the third series of experiments some remarkable phenomena are encountered. This series is a determination of the tensional strength of neat cement briquettes, gauged with water, and stored in

Mr. Hart.

TABLE 1.—PERIODS OF SET OF PATS OF CEMENT; AND TENSIONAL STRENGTH OF VARIOUSLY GAUGED NEAT CEMENT BRIQUETTES.

Alkali.	Percentage.	FIRST SERIES.					SECOND SERIES.							
		Test I.—Periods of set of variously gauged pats, setting in air.					Test II.*—Tensional strength, neat cement briquettes, setting 24 hours in air under damp cloths.		Test III.*—Tensional strength, neat cement briquettes, setting 24 hours in air, under damp cloths, then stored 6 days in water.		Test IV.*—Tensional strength, neat cement briquettes, setting 24 hours in air, under damp cloths, then stored 27 days in water.		Test V.*—Tensional strength, neat cement briquettes, setting 24 hours in air, under damp cloths, then stored 89 days in water.	
		No. of pat.	Initial set.		Final set.		Sample No.	Load.	Sample No.	Load.	Sample No.	Load.	Sample No.	Load.
			Hours.	Minutes.	Hours.	Minutes.								
Na Cl...	0.1	2	3	41	9	2	B	312	N	708	1AA	768	3AA	729
	1.0	3	3	30	8	24	C	343	O	739	1BB	813	3BB	814
	5.0	4	3	31	8	46	D	414	P	833	1CC	733	3CC	647
	10.0	5	3	11	7	17	E	492	Q	741	1DD	645	3DD	645
Na_2CO_3	0.1	6	4	34	9	31	F	283	R	667	1EE	952	3EE	751
	1.0	7	3	14	8	34	G	309	S	677	1FF	815	3FF	926
	5.0	8	0	9	1	22	H	442	T	728	1GG	848	3GG	721
	10.0	9	0	6	2	48	I	421	U	644	1HH	717	3HH	715
Na_2SO_4.	0.1	10	3	38	8	58	J	205	V	628	1II	802	3II	741
	1.0	11	3	17	8	50	K	235	W	718	1JJ	822	3JJ	791
	5.0	12	3	1	8	10	L	251	X	761	1KK	923	3KK	773
	10.0	13	3	0	8	31	M	328	Y	810	1LL	890	3LL	925
H_2O....	100.0	1	3	39	8	26	A	241	Z	725	1MM	867	3MM	855

* Mean results of five experiments.

solutions of chloride, carbonate, and sulphate of sodium, in strengths of 0.1%, 1.0%, 5.0%, and 10.0%, and in water, for various periods of time. The results are shown in Table 2. Mr. Hart.

The results of Test VI indicate an increase of tensional strength, with an increase of solution strength up to 10.0%, when there is a falling off.

The same is shown in Test VII for 27 days, except in the case of the sulphates, in which the 10.0% solution gives the highest tensional strength.

Test VIII shows less uniformity of results, but the enormous strength of the briquettes stored in the stronger sulphate solutions should be noted. Some of the briquettes resisted a tension of 1 400 lb. per sq. in.

So far, no particularly harmful results had occurred from the presence of alkali, but in the fourth series, in which sand briquettes were used, the effect was marked. In this series, one part of cement was mixed with two parts of standard (Ottawa) sand and gauged with water and then stored in solutions of sodium chloride, carbonate, and sulphate. Only one test has been run in this series, which covers 28 days. The results are shown in Table 2.

In Test IX the results are not as uniform as in the case of neat cement briquettes, as might well be expected. They indicate, however, that there is very little weakening in the case of briquettes stored in solutions of chloride and carbonate, but that there was a remarkable weakening in the case of those stored in sulphate solutions. The tensional strengths decrease as the solution strength increases. The briquettes stored in water had a strength of 448 lb. per sq. in., those stored in a 0.1% solution of sodium sulphate, 441 lb. per sq. in., while those stored in a 10.0% solution broke at 58 lb. per sq. in. The appearance of these latter briquettes was much the same as that of the tile, and they could be crumbled in the hands.

These results, although meager, seemed to indicate that sodium sulphate was the deteriorating factor, and that its effect was on the bond between the cement and the sand. This being true, it was felt that the solution of the second part of the problem was to render the cement impervious to water. It was decided to start experiments with that end in view, before any more tests of the action of the alkalies were made.

Obviously, the mere coating of the surface of a concrete structure would not be satisfactory, as the least scratch in such a coat would render the whole structure open to destruction. The real solution lay in actually water-proofing the cement itself.

With this in view, a water-proofing mixture was secured from a St. Louis concern, and a fifth series of tests was run. It was impossible to obtain the mixture alone, but a water-proofed Eastern cement was

Mr. Hart.

TABLE 2.—TENSIONAL STRENGTH OF NEAT CEMENT BRIQUETTES, AND OF 1:2 SAND BRIQUETTES, GAUGED WITH WATER, SET IN AIR, UNDER DAMP CLOTHS, FOR 24 HOURS, THEN STORED IN SOLUTIONS OF VARIOUS ALKALIES, OF VARIOUS DEGREES OF ALKALINITY, FOR VARIOUS LENGTHS OF TIME.

Alkali.	Percentage.	Third Series. Neat Cement Briquettes.						Fourth Series. 1:2 Sand Briquettes.		Fifth Series. 1:2 Sand Briquettes, Using Water-proofed Cement.	
		Test VI.* Stored for 6 Days.		Test VII.* Stored for 27 Days.		Test VIII.* Stored for 89 Days.		Test IX.* Stored for 27 Days.		Test X.* Stored for 89 Days.	
		Sample No.	Load.	Sample No.	Load.	Sample No.	Load.	Sample No.	Load.	Sample No.	Load.
$NaCl$	0.1	I	657	1A	936	3A	841	2S1	372	3W1	317
	1.0	II	682	1B	979	3B	861	2S2	393	3W2	389
	5.0	III	757	1C	1 251	3C	910	2S3	350	3W3	381
	10.0	IV	733	1D	1 055	3D	943	2S4	491	3W4	325
Na_2CO_3	0.1	V	668	1E	920	3E	883	2S5	474	3W5	380
	1.0	VI	702	1F	925	3F	738	2S6	429	3W6	371
	5.0	VII	712	1G	....	3G	799	2S7	423	3W7	348
	10.0	VIII	636	1H	902	3H	848	2S8	373	3W8	376
Na_2SO_4	0.1	IX	647	1I	831	3I	915	2S9	441	3W9	409
	1.0	X	717	1J	899	3J	911	2S10	380	3W10	338
	5.0	XI	807	1K	1 064	3K	1 037	2S11	206	3W11	378
	10.0	XII	787	1L	1 108	3L	1 139	2S12	58	3W12	357
H_2O	100.0	XIII	697	1M	867	3M	838	2S13	448	3W13	414

* Mean results of five experiments.

furnished. The local cements are stronger, in general, and this fact accounts for the apparent discrepancy. In this series the water-proofed cement was mixed with standard (Ottawa) sand in a proportion of 1 to 2, and gauged with water, then stored in solutions of chloride, carbonate, and sulphate of sodium for various periods of time. Only one set of tests has been completed at the present time, the results of which are shown in Table 2. Mr. Hart.

In Test X the results are not as uniform as in the case of the neat cement briquettes, but they show pretty conclusively that there is no serious deterioration after three months.

Since these experiments were begun, Bulletin 69 of the Montana Agricultural College and Bulletin 132 of the Colorado Agricultural College, have been received. These bulletins corroborate many of the writer's observations, but approach the question from different angles.

These experiments are being continued by the writer, and are being extended to include a study of the effect of the waters of the Great Salt Lake, which contain a large percentage of alkaline salts.

The foregoing results are submitted for whatever they may be worth, and no discussion will be attempted by the writer.

Acknowledgments are due to C. G. Elliott, M. Am. Soc. C. E., Chief of Drainage Investigations, U. S. Department of Agriculture, for permission to present this information, and to Dr. William Blum, and Professor E. H. Beckstrand, of the University of Utah, and Mr. O. C. Hart, Chemist of the Utah Portland Cement Company, for valuable information and assistance.

Rudolph Hering, M. Am. Soc. C. E.—This paper is very timely, not only in calling prominent attention to the subject, but in giving some preliminary conclusions which appear to the speaker to be along the right lines. Mr. Hering.

The destructive effect of alkali may be traced partly to alkaline ground-waters coming in contact with a concrete structure, and partly to alkaline waters which may be conveyed in a concrete channel. In both cases, however, there is a water contact.

The effect of acid upon concrete is more complex, and is not alluded to by the author. There are cases where an acid water or an acid sewage has destroyed a cement structure by contact, and also cases where such a contact in no way injured the structure, but where serious injury has been caused by gases above the waters after escaping from them; so that, in one case, the cement has deteriorated only below the water surface, and in the other it has deteriorated only above it.

The great usefulness of cement for water-carrying works, or for foundations in ground-water, makes it quite important and almost imperative to find ways and means of guarding against its destruction by either alkali or acid, and there is no doubt that, at no very distant

Mr. Hering. day, the subject will become sufficiently well understood for all practical purposes.

In the meantime engineers should become acquainted with the facts of experience already known, and the author has done a good work in collating some of them.

The engineer and chemist reporting on the sewer case at Great Falls, Mont., distinctly conclude that "the disintegration of the cement cannot be charged to any action of the sewage or gases from the same." The speaker will refer to the effects of sewage later.

Experiences recorded in Montana, Colorado, and Europe indicate pretty satisfactorily that cement can be completely destroyed by alkaline or acid waters coming in contact with it. Even soft bricks seem to have been affected, but no final explanation is offered. As the same results have followed the use of quite different brands of cement, and in different countries, it may be concluded that the destroying cause is a broader one.

Evidence points strongly to the fact that the porosity of the material aggravates the evil. The mortars used were generally mixed from 1:3 to 1:5, which indicates a sufficient porosity to allow alkaline water to enter by capillarity, and, if under some pressure, as from ground-water standing higher than the drain, to pass through the material into the drain.

The deterioration is generally greater the more porous the mortar, as often found in the interior of the mass, while at the surface the cement often forms a firmer and richer coating, and is very little if at all affected, unless there is merely a white alkaline efflorescence.

These conditions are quite consistent with the conclusion that the surface layers, through plastering and troweling, have been compressed and have had their porosity decreased as the layers were made denser. The absorption of alkaline waters, and therefore their detrimental effect, is correspondingly reduced.

Evidence is available at Great Falls showing that, where the soil in the back-filling over a drain had the highest percentage of alkali, the greatest destruction took place. It is also recorded that the waters flowing in a drain are generally less alkaline than the adjacent ground-waters, which fact is supposed to be probably due to the waters entering the drain having had less time to take up alkaline solutions than the more slowly percolating or standing waters in the soil outside of it.

The author recommends, where practicable, an exclusion of the alkaline soil-waters from a cement drain or sewer by a sub-drain of gravel or stone, which, also, in the speaker's opinion, appears to give the best and cheapest solution.

Professor William P. Headden, of the Colorado Agricultural College, has given a chemical analysis of the original cement and of the material after it had been altered by alkaline water. This is

interesting, as it shows the removal of some and the formation of other ingredients, as follows: Mr. Hering.

Removed:	about two-thirds of the alumina..............	(Al_2O_3)
	about one-half of the silica....................	(SiO_2)
	about one-half of the lime......................	(CaO)
	about one-half of the iron oxide..............	(Fe_2O_3)
Formed:	about 12 times the sulphuric acid.............	(SO_3)
	about 9 times the carbonic acid.............	(CO_2)
	about 3 times the magnesia...................	(MgO)

This shows a large accession of sulphuric and carbonic acids, and the conclusion to be drawn from this alteration is that the most active agent in the decomposition of the concrete was the sulphuric acid of the sulphates carried by the waters in solution, that the carbonic acid came next, and the accession of magnesia last. This result corresponds in general with others derived elsewhere.

It has been known for some time that sea water has deteriorated cement by the action of the sulphates contained in it, chiefly by the final formation of calcium sulphate, which by crystallization expands and mechanically disintegrates the mass. The precaution usually considered is the making of a denser and richer mixture in order to prevent the sea water from penetrating the mass, which conclusion is in harmony with that reached by the author and others for protection against alkaline ground-waters.

The only other preventive seems to be that which is intimated by the author in closing, namely, the external application and a partial incorporation of some impervious coating. Many coatings have been suggested to effect this purpose, and some have been used with moderate success; but, as yet, there is no consensus of opinion regarding the best.

No doubt different coatings may probably be found best under different conditions. Manufactured and thoroughly dried cement pipe may perhaps be coated with a material which would give satisfaction, but would not answer for a pipe made in the trench. The only coating which will give permanent satisfaction is one which will be effective upon a damp structure, and will incorporate itself so thoroughly with the cement that peeling or scaling off is impossible. It is hoped that such a material may soon be found. A lining composed of vitrified tile plates has been proposed for the purpose in the West, and, thus far, barring the expense, it appears to have given satisfaction.

The speaker has mentioned the effect of acid upon concrete structures as being complex, so far as it is governed, not only by an acid in the liquid, but by gases subsequently arising from it. An acid liquid, as in the case of the sewage sometimes discharged from factories, is known to disintegrate cement pipe. The preventive, as in the former case, if practicable, is to exclude the objectionable element, or to give the cement a protective coating or lining.

Mr. Hering. The effects of the gases produce an entirely different condition. The most serious of these is that of the sulphuretted hydrogen which may be converted into sulphuric acid in the sewer above the water, and in some cases, as found in a Los Angeles sewer by the City Engineer, Homer Hamlin, M. Am. Soc. C. E., sulphur crystals adhere to the bricks of which the sewer was built.

The Los Angeles sewage produced no deterioration of the cement below the water surface, the speaker finding it hard and sound. This condition differed radically from the effects of alkaline sewage where the deterioration was chiefly below the water surface. The escaping sulphuretted hydrogen was converted into sulphuric acid within a short distance of its escape from the sewage, as was distinctly discernible on the surface of the brickwork in the arch. This acid transformed the carbonate of lime in the cement joints into sulphate of lime, a soft friable gypsum, which gradually caused the complete destruction of the binding quality of the mortar.

In this case, no doubt, a good forced ventilation might have prevented the formation of sulphuric acid, or the sewer might have been given a vitrified lining, or at some time it may be possible to apply a coating which will protect sewers from this sort of destruction. In Los Angeles, for other reasons, the sewer was abandoned for one built in another locality.

Some interesting experience in this direction is reported from Germany.

In a Berlin brick sewer, where the mortar was a 1:3 mixture, flakes up to ½ in. in thickness and 2 in. in diameter peeled off the bricks. The thickest peeling was at the cement joints. Upon the mortar was observed a soft white material (gypsum) looking like freshly made lime mortar. Below the water level, the mortar and the bricks were sound, as they were in the Los Angeles case.

To ascertain the cause of this trouble, experiments were made by hanging in the sewer, well above the water level, samples of three materials: marble, cement mortar, and pulverized carbonate of lime. The results are given in Table 3.

TABLE 3.

Sample.	Percentage of SO_3.				
	When suspended in sewer air.		When observed.		
			May, 1897.	Jan., 1898.	May, 1901.
Marble	November, 1896	0.019	0.051	0.420	.....
Cement mortar	February, 1897	0.116	0.200	0.440	0.640
Carbonate of lime	" "	0.010	0.048	1.440	2.760

It was found that the sulphuric acid contents in these materials were increased in quantity, as follows: Mr. Hering.

In the marble, in 14 months, about 20 times;

In the cement mortar, in 11 months, about 4 times;

" " " " in 4 years, about 6 times;

In the carbonate of lime, in 3 months, about 5 times;

" " " " " in 11 months, about 140 times;

" " " " " in 4 years, about 250 times.

In the summer of 1901 an analysis of the sewer air gave 200 parts in volume of sulphuretted hydrogen per million parts of air, which was considered an average condition.

At the sewage department of Charlottenburg (Berlin), equal parts of sulphuretted hydrogen and air were passed through cotton at a temperature of 30° cent. (85° Fahr.). Water was then filtered through it, and the presence of sulphuric acid was demonstrated. As a further demonstration, a thin water layer covering the bottom of a closed bottle and containing some fine sulphur powder suspended in it, on being exposed to a temperature of from 20° to 30° cent. for two weeks, showed a strong reaction of sulphuric acid.

That sulphur is formed directly from sulphuretted hydrogen is shown by the fact that sulphuretted hydrogen when dissolved in water frequently shows sulphur powder on the surface formed by oxidation ($H_2S + O = H_2O + S$); and very fine sulphur powder exposed to air and water is known to be directly converted into sulphuric acid ($S + 3O + H_2O = H_2SO_4$).

The Berlin examinations, therefore, give a confirmation of and an explanation for the Los Angeles case. The sulphuretted hydrogen escaping from the sewage rises to the brick arch, which has a coating of moisture condensed upon the surface. The air converts it first into sulphur, and this is subsequently converted into sulphuric acid.

It had been suspected that bacterial action was responsible for the latter conversion, but Winogradski, in his work on "Sulphur Bacteria," reports that he obtained the same result without it.

It is interesting to add that in 1897, when the foregoing experiments began, the bricks were also subjected to analysis. The porosity was found to vary from 8.5 to 14.3% in bricks of different manufacture. All bricks showed on the surface white exudations of carbonate of lime, but they were very slight upon the densest and very marked upon the most porous brick, and in the latter case the pieces could be easily taken off with a knife.

This phenomenon is explained by Bretschneider as follows: From the layer of moisture on the brick the sulphuric acid enters the pores and is diffused by capillarity through fine cracks and the pores into the interior of the mass. It converts the lime into gypsum, which by this conversion is doubled in volume. Unless the material of the

Mr. Hering. brick can resist the resulting expansion, when some of the gypsum oozes out to form a coating, it cracks and peels off, as above mentioned, to the depth to which the sulphuric acid has formed the gypsum.

It has been observed that the destruction of mortar does not progress in an arithmetical ratio, but gradually decreases, as indicated in Table 3. This is partly explained, also by Bretschneider, by the increased ventilation through additional house connections, which in Germany are used as sewer ventilators, the greatest destruction taking place where there were fewest connections. Secondly, he believes that the percolation of ground-water through the sewer masonry gradually decreases by a closing of the pores on the extrados of the arch, and finds that the surface of the bricks on the interior thus becomes dry and the formation of sulphuric acid ceases.

In Osnabruck, Prussia, a sewer was built in peaty ground in 1903, the ground-water level standing about at the springing line. In half a year signs of destruction were visible, and within several years it became serious.* The cause of the disintegration was laid to iron pyrites (FeS_2) which formed 17% of the peat. The greatest destruction was found on the outside of the sewer and between high and low ground-water level, which is explained by the fact that the conditions for an energetic oxidation were most favorable when both air and water were present at the same time. The least destruction, in fact, almost none, was observed in the interior.

This case is explained by some as being due to the pyrites being oxidized in contact with air into free sulphuric acid (SO_3) and sulphate of iron ($FeSO_4$), and by the further fact that the ground-water contained from 8 to 87 parts per million of free sulphuric acid.

The same case is explained differently by Bretschneider. He maintains that the destruction of the cement mortar required that a sufficient amount of sulphuric acid should form directly upon and in the structure, and believed the acid dissolved in the ground-water was too weak for the purpose. He assumed that the sulphuretted hydrogen contained in the ground-water, which is abundant in the peat, rises into the pores of the damp soil around the structure, and is there first converted into sulphur, as above mentioned, and then, after being exposed to more air and more moisture, there is a further conversion into sulphuric acid, when adjoining the structure or when absorbed into the same. It will be seen that in Osnabruck, the disintegration resulted from acid peaty water and also from sulphuretted hydrogen gas.

Structures in Charlottenburg have been protected against injury from sulphuric acid and other organic acids in peat or similar soils by a complete covering of three layers of asphalt paper.

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* City Engineer Lehmann, in *Deutsche Bauzeitung*, 1908, p. 467.

Mr. Hering.

The foregoing data seem to indicate the following inferences:

1.—When the immediate agent of destruction is carried by water, disintegration will be found below the permanent water surface. If such water is flowing inside of a structure, as in a sewer (acid or alkali factory waste), the disintegration will be inside and as far as the water penetrates the material. If the water is ground-water in alkali soil, swamp or peat, the disintegration will be on the outside (Great Falls and Osnabruck), and chiefly between high and low ground-water levels, and may penetrate porous material toward the inside of the structure.

2.—When, on the other hand, the agent of destruction is caused by gases (generally sulphuretted hydrogen) arising from waters, whether on the outside (Osnabruck) or the inside (Los Angeles and Berlin) of a structure, the disintegration will take place above the permanent water surface.

Mr. Bates.

PHILO H. BATES, ESQ.* (by letter).—Mr. Anderson's paper on the effect of alkali on concrete, gives an interesting résumé of the subject. One noticeable feature is the agreement by all that this action is similar to, or identical with, that of sea water in effecting the disintegration of concrete. This may be true, for in alkali, alkaline waters, and sea waters, the same salts are found, though the proportions of the salts are very different, as, for instance, the very slight quantities of chloride and the large quantities of sulphates in alkaline waters, and the reverse in sea water. Which of these salts causes disintegration, or which is the most active in this respect, however, is a matter of considerable doubt.

The Structural Materials Testing Laboratory of the United States Geological Survey has recently undertaken some experiments which are still under way, and by which it is hoped to define what salts or combinations of salts cause disintegration of concrete and kindred structural materials. Moreover, it is hoped to determine whether this action is caused by chemical or physical changes, the former resulting from the reaction of the salts in solution with the constituents of the cement, and the latter from the freezing or crystallizing of the salts from their solutions in the pores of the concrete. Many engineers are acquainted with the action of the freezing of water in concrete, and its results, where there is no chemical reaction. Without acknowledging any chemical reaction, it can be readily understood that the result of the formation of crystallizing salts in concrete is to cause them to occupy a greater volume than their solutions. Chemical action does take place, however, when the magnesia salts are present in the solution, as the lime liberated from the cement by its setting replaces the magnesia, the latter appearing as a gelatinous mass. It might be con-

* Chemical Engr., Technologic Branch, U. S. Geological Survey.

Mr. Bates. sidered that this mass thrown out over the particles of cement would protect it from further action. The salts in black alkali, largely sodium carbonate, have a chemical action which involves the formation of calcium carbonate.

Bulletin No. 132, of the Montana Agricultural College, gives an excellent description of the condition of the sewers in Great Falls, which city is located in a very alkaline region, where the salts are sodium or magnesium sulphates, or combinations of these two. It is noticeable that these sewers are principally of brick, and that they are badly disintegrated. This brings up a feature which has been little emphasized before, namely, the action of salts on brick and stone. No matter whether the action is physical or chemical, it cannot be assumed that concrete will be attacked and not other porous material. The writer has seen samples of brick and sandstone, removed from buildings in Great Falls, which could be powdered in the hand. He has also examined the bottom of irrigation ditches excavated in Oregon sandstone, in which the stone has retained its original form and appearance, but could be crushed readily in the hand. It would seem, therefore, that the problem is not limited to cement products, but should include all building material which might be used in a similar manner. Consequently, in its investigation of this destructive action, the Geological Survey has included also building stone and clay products.

In the investigations now under way, there are being used, in the preliminary experiments, solutions of sodium chloride, sodium sulphate, sodium carbonate, magnesium chloride, magnesium sulphate, and iron sulphate alone; also solutions containing equal parts of sodium chloride and sodium sulphate; sodium chloride and magnesium chloride; sodium chloride and magnesium sulphate; sodium sulphate and magnesium sulphate; magnesium chloride, magnesium sulphate, sodium sulphate, and magnesium chloride; and also sea water from Atlantic City.

These solutions are being used in two series of investigations; the first, purely chemical, consists in shaking up a definite quantity of cement with a definite quantity of solution, then withdrawing the solution at intervals, and, by analysis, determining what the cement has lost or gained. At present this is being conducted with an unset cement. Later, the test will be repeated with a set cement. The second series is physical, and consists of making hollow cylinders of cement mortar and hollow cylinders of burned clay, closed at one end. Through these the various solutions are allowed to percolate, the appearance of the cylinders being noted from time to time. From this the relative disruptive force of the different solutions may be determined. In the first experiments of the second series a very rich mortar was used, dry mixed, in order to give a very porous product,

rich in cement. From this it will be possible to determine whether any of these salts can be omitted in the further investigations owing to their slight action. Hereafter, other cement mortar cylinders will be made, less rich and more dense mixtures being used. Specimens will also be made to which, after setting, different quantities of salts will be added in solution, and an attempt made to determine how much is necessary to cause disruptive action. By keeping other cylinders immersed in the various solutions, and noting the action or want of action, and then drying and noting the effects, it is hoped that some valuable preliminary information will be procured on this interesting and difficult problem. Mr. Bates.

The very dry atmosphere of the region where alkali is most plentiful and where the action has been reported to be most severe, naturally suggests that it would cause excessive evaporation and result in excessive crystallization.

These investigations are being prosecuted in the hope that a method of preventing this action may be evolved. This will necessitate tests of various water-proofing materials, and these have been in progress by the United States Geological Survey for more than a year. A very important class of these materials, known as bitumens, and including coal-tar, pitch, asphaltum, and petroleum residuum, is being examined. The investigation would also be incomplete without considering the use of pozzuolana, slag, and iron-ore cements alone or replacing a portion of the Portland cement.

Thomas H. Means, M. Am. Soc. C. E. (by letter).—This paper brings before the Society a subject which is worthy of careful consideration. Recently a number of articles have appeared in the public and engineering press, which would lead the uninitiated to believe that, in the soil of the West, concrete is not permanent. That there is no need for such apprehension is apparent, of course, to anyone well acquainted with the circumstances, but there are so many people who are not, that a few words of reassurance may not seem amiss. Mr. Means.

This subject was brought prominently before the public in bulletins issued by the Experiment Stations of Montana and Colorado. Each of these publications describes cases of failure of concrete, and each presents the results of some chemical work.

It is unfortunate that the results of these investigations, made on specific cases of failure of concrete, should have been given such general application. No general failures have occurred in the West, in fact, there have been very few, when the great extent of cement structures in engineering work is considered. For many years cement has been used in irrigation and drainage work in arid and semi-arid regions, not only in the United States, but the world over, and very few failures have been reported.

Mr. Means. For nearly twelve years the writer has been associated with work in the Arid West, much of the time in connection with alkali-soil investigations, and, during this period, work has been carried on in every arid State. From the first he has watched the effect of various alkalis on cement, brick, stone, and other building materials. However, no special investigations were made in order to solve the problem. Wherever a certain alkali has been found, a deleterious action on cement has been noticed. The severity of this action seemed to depend on the quality of the concrete, on the strength of the alkali solution, and, to a certain extent, on the exposure of the concrete. Other alkalis do not seem to have any serious effect on concrete, in fact, a number of cases have been under observation where concrete has been exposed for several years to intensely alkaline soils with no bad results.

The alkali which seems most harmful generally contains sodium and magnesium sulphates, chlorides, and some gypsum or calcium sulphate; other salts occur in greater or less quantity.

As far as observations without analyses are of value, it is apparent that the magnesium soils are the most deleterious, and this view is supported by the experience of others. Chlorides alone do not seem to be harmful, and sulphates of sodium and calcium are not harmful. On the Truckee-Carson Project, in Nevada, there are areas of land which contain large quantities of sodium sulphate and sodium chloride mixed. On this project a great many concrete structures have been built; 50 000 bbl. of cement have been used, some of it having been placed in strong alkaline soils, and a careful examination of structures five years old has failed to reveal any disintegration of the concrete.

Carbonate of soda or black alkali is the most harmful salt, as far as vegetation is concerned, and it is likewise the only alkaline compound, in the chemical use of the term, ordinarily found in soils. It has been said that this salt, on account of its alkaline reaction, would have a solvent action on cement, but such does not seem to be the case. Apparently, black alkali alone is not harmful to concrete. Big Soda Lake, near Hazen, Nev., is an important source of natural soda. The water carries about $12\frac{1}{2}\%$ of solids in solution, and of this more than 7% is sodium chloride, nearly 2% sodium sulphate, and more than $2\frac{1}{2}\%$ sodium carbonate. Specimens of cement pipe, which have been in contact with this water for several years, show no signs of deterioration.

It is true that very porous concrete is apt to be damaged by alkaline waters of any kind, but good concrete seems to be free from damage by any but alkali containing magnesium salts. No evidence is at hand to show that any particular brand of cement is more susceptible

to damage than others, but it is not to be expected that such would be true, for all reputable brands have nearly the same composition. Mr. Means.

Besides the chemical action which magnesium compounds seem to have, there is a mechanical disintegration which seems to be most active in porous concrete. The crystallization, solution, and recrystallization of salts seem to loosen up the concrete and disintegrate it by prying off outside grains.

The harmful alkalis seem to be found almost always in certain cretaceous formations of the Rocky Mountain States. Pierre shale and formations associated with it, seem to be the main source of soluble magnesium salts. This geologic formation occurs in a number of Western States, and where the soluble salts have not been leached from the soil, cement and concrete work is apt to be badly affected.

No doubt there are other localities where deleterious compounds exist. Evidence of this can often be obtained from the State Experiment Stations or from the Department of Agriculture, at Washington.

Thus far, no very satisfactory remedy has been proposed. There is an excellent opportunity for an extended investigation of the physical and chemical phenomena connected with the effect of alkali on concrete. Magnesium compounds seem to have many peculiarities. It may be possible that a cement of some peculiar composition may be developed, which will not only resist the disintegration and decomposition caused by magnesium salts, but will be more satisfactory for use in sea water. Again, it may be possible either to protect concrete made with commercial brands of cement, by some special precautions, or to introduce some foreign substances into it in order to prevent damage. The field certainly looks promising for some enterprising chemist or physicist.

F. E. ROBERTSON, ESQ. (by letter).—Alkali is to be found in many parts of India, where it is known as *reh* and *oosur,* and regular alkali deserts occur in Sind and on the Northwest Frontier. Under certain circumstances the salt is most destructive to materials which would stand well enough ordinarily, but the cause and remedy are well known. The salt crystallizes in the pores of the material and disintegrates it by an action somewhat similar to that of frost. Bricks are speedily reduced to powder, as are also soft stones and concrete. The mortar used in those parts of India where alkali occurs, is made of one part of fat lime ground finely with two parts of pounded brick, called *soorkhi*. It is moderately hydraulic and well made, and, when laid, eventually becomes as hard as bricks; it is likely to be destroyed, however, by the effect of alkali. Even fire-clay goods, if underburnt, are likely to be destroyed, one end of a pipe being reduced to powder while the other end remains uninjured. For building, and for making *soorkhi,* nothing should be used but slightly vitrified brick—at all Mr. Robertson.

Mr. Robertson. events on all external surfaces—and concrete with an impervious skin.

The author states that:

"These failures may indicate some special peculiarity of the local soil, and may be somewhat similar to the well-known fact that the action of sea water has been destructive to concrete in certain localities and not in others."

In regard to this, it is not the action of the alkali or the sea water which varies from place to place, but the structures acted on. Underburnt brick and porous concrete will perish whenever they come in contact with alkali or sea water.

The tile mentioned as made of 1:5 mixture was certainly very porous, and it is improbable that the voids in any sand are less than one-third, which, to be safe, would demand a mixture of 1:2½.

Mr. Morse. George F. Morse, M. Am. Soc. C. E.—This paper merely touches on the subject of alkali in water used for mixing concrete, and though the following statements cannot properly be called a discussion, it is thought that they are of enough interest to the Profession to be recorded.

While building concrete piers for a railroad bridge across the Arkansas River, near Muskogee, Okla., an instance came to the speaker's attention which seemed to indicate that alkali alone in the water used in the mix does not always have a detrimental effect on the concrete. In this case, two piers, identical in every way, except for the coarse ingredient used, and built simultaneously, showed very different results. One pier was built of gravel taken from the river bed, which produced a good concrete. The other pier was built of Joplin, Mo., chats, and was a total failure, as the concrete did not set. The pier was afterward taken down. The "concrete" was of about the consistency of semi-cemented gravel, and was easily excavated with pick and shovel. In both instances water containing alkali (and from the same source) was used, the sand and cement being identical.

Subsequent experiments with the chats, using water free from alkali in the mix, produced excellent results; but, when alkaline water was used the concrete failed to set. The same result was obtained in three other instances, where similar conditions prevailed.

Attention is called to the fact that in the Southwest chats are very commonly used in making concrete, with excellent results; in fact, the speaker had used them in reinforced concrete work before these bridge piers were constructed. If it had not been so evident that the chats were at fault (as shown by the opportunity to compare the result with concrete containing other coarse ingredients), there would have been no reason to suspect the real cause of the failure.

It is customary for engineers to look well to the character of the

cement, sand, and water used in concrete work, and to be satisfied with the coarse ingredient, if it answers the physical requirements. It is evident from the foregoing that in this case some chemical action between the alkaline water and the chats caused failure. Mr. Morse.

RICHARD H. GAINES, ESQ.*—Interest in this subject is not confined to the West. The evidence presented by the author abundantly demonstrates the destructive action of alkaline waters on cement, tiling, and concrete. The question is no longer one of bad specifications or poor construction; but special measures of protection, yet to be devised, are necessary to meet the conditions outlined. A difficult problem is submitted to the Engineering Profession, and the vital importance of its solution cannot be emphasized too strongly. Few are aware of the extent of the great region, west of the Mississippi, which is marked by the presence of alkali in the soil or on the surface. Mr. Gaines.

The decomposition of mortars exposed to the action of waters charged with sulphates has long occupied the attention of chemists and engineers, and many experiments have been made in order to discover some hydraulic binding material which would not be subject to deterioration. Until within a few years, these researches have been concentrated chiefly on the injurious action of sea water, although the destructive effect of sulphates of lime and magnesia was not unknown. The difference between sea water and the alkaline waters of the West is that the latter act more energetically, owing to a much greater concentration of the sulphates of magnesium and calcium, and, as their name implies, they contain, in addition, alkaline carbonates.

Notwithstanding the title of the paper, nothing is said of the effect of the presence of the alkali constituents of the waters. These strong bases react with the aluminate in cement, resulting in acid-forming oxides.

It is desirable to have a clear conception of the chemical changes which tend to destroy concrete when in contact with sulphate or alkaline waters. The basic calcium aluminate in set cement is believed to be the vulnerable point of attack, and is where the mischief is done. With this constituent the sulphates form sulpho-aluminate of lime, a reaction attended with a great increase in volume (owing to the water taken into combination), and consequent disruption. Both magnesium and calcium chlorides, wherever present, are detrimental to concrete, owing to the fact that the chlorine radicals replace the aluminate, causing the production of soluble compounds. In a series of experiments on immersed briquettes with artificial solutions of various salts, recently conducted by the speaker, the injurious action of chlorides of calcium and magnesium was fully confirmed. Sulphate solutions, however, appeared from the experiments to be the most active decomposing agents.

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Mr. Gaines.

The experience cited, of numerous concrete failures in the West, teaches that engineers must be on the alert for saline waters wherever construction is planned or under way. In fact, waters almost saturated with salt solutions are sometimes found far from alkaline regions or any recognized occurrence of gypsum. On the other hand, drain waters which, at certain times, contain small quantities of sulphates, may become saturated during periods of drought. Subterranean waters should always be examined for sulphates and chlorides of calcium and magnesium, if they are to flow in contact with concrete. Waters encountered in the older strata in several parts of the country, both East and West, have been found to be heavily impregnated with these injurious compounds.

According to the partial analyses published, the ground and drain waters from the trans-Mississippi region do not differ greatly in composition from the sulphate waters which have proved destructive to mortars in Spain, France, and other parts of the world. In France, especially, considerable attention has been given to the study of this problem during the last few years, and some valuable results have been obtained. There, it has been found that the pozzuolanas have always had a notably ameliorating effect where sulphates were encountered. The best resistance values were obtained with mixtures of silicious cement and dehydrated clay in the proportion of 1 part of clay to 1 part of cement. Calcined clay seems to be the most energetic of all the artificial pozzuolanas. Vicat estimated the appropriate calcination temperature of clay at about 1 000° cent., but it should be emphasized that the operation of dehydration is industrially a delicate one; if the desired temperature is not realized, either by exceeding or by not reaching the proper calcination heat, an inert material instead of a pozzuolana may be manufactured.

Experiments by M. Bied, of Le Teil, Department of Ardèche, France, reported to the last meeting of the International Society for Testing Materials, confirm the superiority of silicious cements over aluminous cements, and the favorable effect of the addition of dehydrated clay. According to Bied, in the presence of sulphate of calcium, the use of dehydrated clay is the only means known at present of preventing decomposition. The addition of the clay cannot be made on the work, but must be entrusted to conscientious manufacturers. The addition of stearate of lime and similar compounds to ordinary cement, which render the mortars more impermeable, were shown to be inefficient in preventing decomposition.

For a number of years the large French company, the Société J. et A. Pavin de Lafarge, claims to have supplied an indecomposable cement based on a mixture of dehydrated clay and the silicious cements made by that firm. This engineering and contracting company constructed the great military harbor works at Bizert, the French

military base opposite Corsica, on the African Coast, and is well known in Europe. The cement made by this firm has been used throughout the gypsiferous territories of Southern France. Mr. Gaines.

The promising results obtained in France should lead to experiments along the same lines in America, and such experiments should be made in as many laboratories as possible. A method, at once sure and rapid, of determining the capability of cement mortars to resist the decomposing action of alkaline or sulphate waters has not come into general use. The method hitherto used commonly consists simply in immersing the mortar in the saline water and observing it for as long periods as possible. The results obtained by this test vary, however, according to the composition of the mortar and the conditions of its immersion, and the experimenter often has to wait long periods before signs of disintegration are observed, and even then such signs may be of a doubtful nature. There is room, therefore, for the proposal of some scientific and expeditious method of arriving at the relative resistance values of different hydraulic materials which may be subjected to the action of sulphate or sea waters.

Until a cement is discovered which is proved to be capable of permanently resisting the destructive effects of these alkaline waters, the safest policy will be to follow the recommendation of Candlot concerning sea water, and to consider their action from a purely physical standpoint. By thus eliminating the chemical side of the problem, the only remedy to be adopted against decomposition is some physical means of preventing the water from penetrating the mortar.

The speaker recently had occasion to study the possible effect on concrete of a deep subterranean water which was heavily charged with the sulphates and chlorides of alkali and alkaline earth metals. Preliminary experiments having indicated energetic decomposing action on hardened cement mortar, a series of accelerated tests was made in order to determine what salts present in the water set up the destructive chemical changes. After ascertaining by analysis the saline constituents of the water in question, a number of definite solutions of chemically pure salts were prepared, each containing separately, in distilled water, the individual constituents found in the natural water. Broken neat and mortar briquettes were immersed in beakers in these solutions and allowed to remain at room temperature for 10 days. For comparison, specimens were kept in some of the subterranean water for the same length of time. The list of pure salts in separate solution included:

Magnesium sulphate,
Calcium "
Sodium "
Calcium chloride,
Magnesium "
Sodium "

Mr. Gaines.

The tests also included the action of salts not found in the natural water, but commonly occurring as constituents of other saline waters that have proved destructive to concrete. These were the sulphates of iron and aluminum, the carbonates of sodium and potassium, and the bicarbonate of sodium.

At the end of the test period, precipitates were found in all the beakers in which the mortar specimens had been in contact with solutions of sulphates, the action having been most energetic in the presence of sulphates of calcium and magnesium. Considerable precipitation also occurred from contact with the magnesium and calcium chloride solutions, the latter proving as actively decomposing as any of the salts. The alkaline carbonates were apparently without effect, as also was sodium chloride, but sodium bicarbonate caused some action. In none of the separate solutions was the decomposing action comparably as energetic as resulted from contact with the subterranean water, which, as previously stated, contained a natural mixture of chlorides and sulphates of calcium, sodium, and magnesium. A qualitative examination of the solutions and material thrown down from the mortar specimens in the form of precipitates, in the beakers where action was apparent, showed that the alumina, lime, and iron oxide in all the specimens had been attacked to a greater or less extent by the solutions.

While the conditions of this series of experiments were not such as to lead to definite conclusions in a quantitative sense, the results obtained serve to show from what ingredients in saline waters danger may be expected; and thus they have a very direct bearing on the study of the question of the effect of alkaline, sulphate, or sea waters on concrete.

Several authorities, including Michaelis, have stated that if alumina in cements is replaced by ferric oxide, the deleterious effect of sea water is prevented. Brief experiments made by the speaker with a sample of so-called iron ore cement received from Germany (in which ferric oxide almost wholly replaces alumina), indicate that while this material is apparently unaffected by sulphate waters, it offers no greater resistance to the attack of calcium and magnesium chlorides than ordinary Portland cement. In practice, whatever cement may be used, all alkaline and sulphate waters should be kept from contact with fresh concrete until it has gained substantial strength.

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PAPERS AND DISCUSSIONS

THE IMPROVED WATER AND SEWAGE WORKS OF COLUMBUS, OHIO.

Discussion.*

By Messrs. Joseph W. Ellms, Julian Griggs, C.-E. A. Winslow, R. D. Scott and R. F. McDowell, Samuel Tobias Wagner, J. Corbett, W. R. Copeland, W. A. Sperry, J. W. Sole and C. P. Hoover.

Joseph W. Ellms,† Esq. (by letter).—The very complete tables of cost of construction submitted by Mr. Gregory are of much value. The total and unit costs relating to the Water Purification Works were of particular interest to the writer in connection with a similar table compiled from the costs of construction of the Cincinnati Filtration Plant. It is obvious that no strict comparison of the costs of similar parts of these two plants is justifiable, since each was designed to meet local conditions. At Cincinnati the plant was required to clarify and purify a turbid water; at Columbus the same conditions were to be met, but, in addition, the water was to be softened. Apparently, the latter function was considered as governing the design of the works at Columbus. Mr. Ellms.

Table 19, showing the costs of construction for the Cincinnati Filtration Plant, is submitted as a contribution to the general subject, and may be of interest to engineers designing and building plants of this type.

* This discussion (of the paper by John H. Gregory, M. Am. Soc. C. E., printed in *Proceedings* for January, 1910, and presented at the meeting of March 2d, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Superintendent, Cincinnati Filtration Plant.

Mr. Ellms.

TABLE 19.—TOTAL AND UNIT COSTS OF MAIN FEATURES OF WORK DONE IN CONSTRUCTION OF WATER PURIFICATION WORKS AT CINCINNATI, OHIO.

Capacity of Plant: 112 Million Gallons in 24 Hours.

Work.	Total cost.	Cost per million gallons of capacity for 24 hours.
Preparation of grounds	$33 359.67	$297.85
Pipe lines between settling reservoirs and head-house	55 354.77	494.24
Head and chemical house	141 989.85	1 267.77
Coagulation basins, gate houses and pipe lines	304 913.05	2 722.44
Filters, filter house, piping, sand and gravel	592 112.30	5 286.71
Piping, valves and gate-house between filters and clear-water reservoir	29 701.91	265.20
Clear-water reservoir	121 332.39	1 083.59
Total	$1 278 793.94	$11 417.80

At Columbus, the unit costs per million gallons of capacity in 24 hours appear to be considerably greater for the settling basins and mixing tanks combined, than for the coagulation basins at Cincinnati. The figures for the Columbus tanks and basins are $7 100 per million gallons of capacity, as compared with $2 722 at Cincinnati. In a general way, these parts of the two plants correspond; but it should not be forgotten that at Columbus more elaborate baffling of tanks and basins, more divisions of the flow of the raw and treated waters, and more places for the primary and secondary applications of chemical solutions were needed and provided for, than were required at Cincinnati. The greater combined unit costs of the head-house, lime-saturator house, storage-house, wash-water tank, offices and laboratories at Columbus, than for the corresponding head-house, chemical-house, wash-water tank, offices, and laboratories at Cincinnati, are similarly explained by the necessity for designing a plant for softening, as well as for clarifying and purifying the water. The combined unit costs for the items noted above for the Columbus plant amount to $3 784, as compared with $1 268 for the Cincinnati plant.

The filters and piping in the Cincinnati plant cost more per million gallons of capacity than did those at Columbus. The figures for Columbus, which include the air-washing equipment, are $3 540, as compared with $5 287 for Cincinnati. However, the filtered-water reservoir at Columbus cost more than that at Cincinnati. The figures for the Columbus plant are $3 280 per million gallons, and for the Cincinnati plant, $1 084. At the latter plant, the clear-water reservoir is a separate uncovered reservoir, while at Columbus, it is directly under the filter tanks, which latter form a protecting roof.

Virtually, no great difference in costs exists, if the cost of the filters, piping, and clear-water reservoir of each plant be combined and then compared. Mr. Ellms.

The cost per million gallons of capacity for the whole purification plant at Columbus is stated to be $17 750, which amount does not include engineering; the corresponding figure for the Cincinnati plant, as shown above, is $11 418, and this also excludes the cost of engineering. The difference of more than $6 000 per million gallons of capacity is doubtless due to the additional requirement demanded by the local conditions at Columbus, that is, for the softening of a very hard water, and one which is at times subject to rapid fluctuations in its physical characteristics.

Julian Griggs, M. Am. Soc. C. E. (by letter).—This descriptive record, with the liberal illustrations showing the details of construction of the improved water and sewage works at Columbus, Ohio, forms a valuable addition to the rapidly growing accumulation of literature pertaining to municipal sanitation. Therefore, it should prove welcome to all who are interested in the subject, and especially to that wide circle of progressive engineers and city officials who since 1904 have followed more or less closely, by pilgrimage or otherwise, the development here being realized. Mr. Griggs.

Columbus is to be congratulated on having works in which the highest state of the art of water and sewage purification was represented at the time they were designed.

The mechanical execution of the work was also of a high order of excellence, and reflects great credit on the contractors and the engineering organization in responsible charge of its construction.

The elasticity of the design is proving of value in affording a wide range for varying the details of operation and thus permitting sundry experiments by the chemists in charge, which will ultimately add to the knowledge on many obscure questions of rates and efficiency, a feature which the writer hopes to see emphasized in the discussion on this paper.

One defect in the sewerage system and sewage purification works to be regretted is in the sand-catching appliances. It seems to the writer that some mechanical device for cleaning and keeping clean the sand-catcher at the main sewage pumping station should have been installed, for the reason that dependence on hand-cleaning has been found to be unreliable. Soon after the operation of the pumping station was begun, the sand-catcher filled to the flow line of the sewer. Since then all detritus arriving in the sewer has been carried forward into the sump chamber where it clogged the sewage-level indicators, and the portion which remained has had to be removed therefrom by hand-cleaning at more or less frequent intervals. Probably half of the detritus carried to the station in the sewage

Mr. Griggs. passed the pumps and was later deposited in the primary septic tanks, where, forming layers over the septic sludge, it confined the gases of decomposition and greatly increased the violence of the ebullitions, thus complicating their action. It still remains to be disposed of.

In this connection it may be of interest to state that the interceptors, some twenty in number, on the intercepting sewer are for the most part only pits, 1 or 2 ft. in depth, in the bottom of each combined sewer, with pipes varying from 6 to 15 in. in diameter leading from the pits to the intercepting sewer beneath the combined sewer at the point of crossing. It is apparent, therefore, that each intercepting pit acts as a sand-catcher for detritus and quickly conveys it to the intercepting sewer. This condition is somewhat mitigated by the fact that in flood flows the smaller interceptors become clogged, and, in that event, a portion of the detritus is carried past the interceptor to the river outlet of the combined sewer.

Three of the interceptors are provided with automatic gates controlled by floats which close the connection to the intercepting sewer at times of storm flow, when, presumably, the greatest proportion of the detritus would be carried in the sewage. These devices have served the purpose intended. It may be that now, however, a new condition has been introduced, which renders them less effective than formerly. The new condition is the daily use of compressed air street flushers, first introduced in 1904; and now, weather permitting, 3 miles of 30-ft. streets, or an equivalent area, are washed daily. These flushers simulate the condition of a heavy shower for the area over which they operate, and carry into the sewer catch-basins and the sewer itself a large quantity of detritus. In the area flushed there are 518 street catch-basins, mostly of the standard pit type, 3½ ft. in diameter, and 1½ ft. deep below the siphon outlets; but 9% of these catch-basins are direct inlets furnished with the so-called Palmer valves. As repairs are needed, these basins are being gradually changed to the standard form with pits.

The intercepting sewer is 6.8 miles long and from 2½ to 6 ft. in diameter, with a grade of 1 per 1 000 at its largest diameter, giving a velocity of 4.8 ft. per sec. It was first put into operation in August, 1894; five years later, in September, 1899, a cleaning of it was begun, which was continued until June, 1900, whereby deposits of from 10 to 15 in. in depth were removed from about 2.4 miles of sewer at a cost of $1.78½ per cu. yd., or a total cost of $6 564.81. Nine years later, in July, 1909, deposits upward of 3 ft. in depth having accumulated, a second cleaning was begun and is being continued.

While the intercepting sewer is being hand-cleaned it is necessary to close the interceptors and divert the raw sewage into the river, fouling the same, and thus defeating for a time the purpose for which the sewage purification works have been constructed.

Mr. Griggs.

The cleaning of the intercepting sewer with sewage accumulated under a considerable head in manholes at frequent intervals and suddenly released through quick-opening gates has been proposed, but while this method is effective in small sewers, it is doubtful whether it would be in sewers of large diameter unless the accumulation of sewage was augmented by storage greatly in excess of manhole capacities.

The fact that the intercepting sewer is about 5 ft. lower than low stages of water in adjacent streams suggests a connection with the same for flushing purposes, and for the upper end of the sewer such a provision should prove of benefit.

Whenever the intercepting sewer has been cleaned the sand has been found cemented in layers with tar which has escaped from the gas-works of the Ohio Penitentiary. An interceptor in the street. on the house sewer from the penitentiary, was built in 1900 and was cleaned five times in that year of from 6 to 8 bbl. of tar at each cleaning. It may be that in the changes occurring since in State and city officials, this provision for preventing tar from entering the sewers has been overlooked.

The advisability of constructing sand-catchers at each of the sewage interceptors to prevent part of the detritus from entering the intercepting sewer, and another sand-catcher on the intercepting sewer east of the river, where the sewer invert is above the back-water and the sewer itself has a shallow cover, is being considered, but whatever may be done in these respects the writer believes that some mechanical device for cleaning and keeping clean the existing sand-catcher near the main sewage pumping station will be found desirable and necessary.

Mr. Winslow.

C.-E. A. Winslow, Esq.* (by letter).—All who are interested in sanitary matters must feel indebted to Mr. Gregory for this comprehensive and detailed account of the important developments in water and sewage practice which have been worked out at Columbus, Ohio. Profitable discussion is suggested by many points in connection with both of the new plants, but the influence of the Columbus experiments and designs on the history of sewage purification is the particular phase of the subject which appeals most strongly to the writer.

Progress in sanitary engineering in the United States has been marked by half a dozen striking and epoch-making investigations. In water purification, the construction of the Lawrence filter, in 1893, the Louisville experiments in 1898, and the disinfection of the Jersey City water supply in 1908, form notable landmarks. Modern sewage purification began at the Lawrence Experiment Station of the Massachusetts State Board of Health in 1890. Then for fifteen years the lead was taken by English engineers; and the report by George A.

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Mr. Winslow. Johnson, Assoc. M. Am. Soc. C. E., on the Columbus experiments in 1905 marks the next really important and fundamental advance in American practice.

The Columbus experiments, followed by the construction and operation of the 20 000 000-gal. plant, demonstrated that the trickling or sprinkling filter could be operated successfully under American conditions, and in a moderately severe northern climate. Since 1905 the opinion has rapidly gained ground that, under ordinary conditions, and with the possible exception of small cities situated where sand is easily available, the trickling process is the most economical of all methods of sewage purification. The plants at Washington, D. C., and Reading, Pa., are obviously modeled after the Columbus studies; and experimental work at Boston, Baltimore, Philadelphia, and Chicago, tends in the same direction.

There are minor points in the design of trickling filters, which remain to be worked out, of which the method of distribution is undoubtedly of the first importance. In regard to this the writer is inclined to believe that the Columbus model will be modified considerably in future plants. The discharge of sewage from fixed sprinkler nozzles with large circular orifices tends to be defective, for two reasons: The quantity of sewage discharged on the wetted area from such a nozzle is too large for efficient purification; and the distribution is notably uneven. At Columbus the first objection has been met by intermittent operation (the bed being dosed at first for 6-hour periods and finally for periods of only 15 min.), and by reducing the diameters of the nozzle orifices on six of the filters from $\frac{9}{16}$ in. to between $\frac{15}{32}$ and $\frac{7}{16}$ in. The second difficulty, of uneven distribution within the wetted area, has been met by operating the nozzles under three different heads, during successive 15-min. periods. If a varying head must be used, however, it seems more reasonable to adopt a nozzle like that designed by W. Gavin Taylor, M. Am. Soc. C. E., to discharge in a sheet rather than over a ring; and Mr. Taylor's nozzle has the further advantage of covering approximately a square and avoiding waste area or the overlapping of circles. If varying head is not to be used, the Technology gravity distributor, in which the sewage is discharged downward on a disc from which it splashes up and out, gives a more even distribution than any fixed device, except nozzles like those used at Birmingham, which have the defect of very small openings subject to serious clogging.

There is no doubt, on the whole, that the trickling filter furnishes a cheap and satisfactory method of securing organic stability. It is an ideal oxidizing machine. The problem of suspended solids, however, it does not solve; and this remains the most serious problem in sewage disposal. The analytical data for the operation of the Columbus plant for 1909, given by Mr. C. B. Hoover, are the basis

for the figures in Table 20, which indicate the extent of this problem in a striking manner. The figures for the mean daily flow through Mr. Winslow.

TABLE 20.—SUSPENDED SOLIDS AT COLUMBUS, 1909.

	Mean daily flow, in millions of gallons.	SUSPENDED MATTER REMOVED (INFLUENT MINUS EFFLUENT).		
		Parts per million.	Pounds per day.	Tons per year.
Septic tank	11.1	118	10 892	1 777
Sedimentation tanks	5.8	43	2 072	338

the sedimentation tanks have been calculated from the data relating to the percentages of the time these tanks were in service, assuming that the periods were representative ones. It appears from Table 20 that 2 115 tons of dry solid material are annually removed from the Columbus sewage, amounting to about $\frac{1}{3}$ ton per 1 000 000 gal. A part of the 1 777 tons deposited in the septic tanks will of course be liquefied, but probably not more than half. Mr. Hoover's figures indicate that four of the tanks were cleaned twice during the year, and the other two four times. At present Columbus is fortunate in being able to discharge its sludge into the Scioto River at periods of high water. For cities not so well situated this question of sludge disposal remains a very real one.

There are two main lines along which the solution of this problem may perhaps be sought profitably. The first is the perfection of the septic tank, or some other form of biolytic chamber, so that a larger proportion of the sedimented solids may be eliminated by microbic digestion. The writer has become convinced that the principal factor which prevents more complete solution of suspended solids is the over-septic condition of the sludge due to the accumulation of waste products of bacterial life. If this be the case, tanks built like the Hampton and Ems tanks, in such a fashion as to separate the sludge from the flowing sewage, keeping the sewage fresh and the sludge as stagnant as possible, are designed on a diametrically wrong principle, as far as the sludge solution is concerned. At the new experiment station of the Massachusetts Institute of Technology, the reverse principle has been applied. A septic tank has been constructed on the Dortmund pattern, the influent entering near the bottom and being skimmed off at the top, so that the sludge is constantly washed and kept from an over-septic condition by the incoming sewage. No data as to sludge digestion are as yet available, for the tank, thus far, has been operated (8 months), without the necessity for cleaning; but the effluent is of excellent character.

Mr. Winslow.

The other possible avenue of approach to the sludge problem lies along the line of utilization. The history of sewage purification is one long story of disappointment as to the extraction of any useful by-products; yet the failures of the past cannot limit the possibilities of the future. Reports of the results already achieved in England and Germany by the reawakening of efforts along this line are not very convincing. It is possible, however, that some mechanical improvement may at any time bring the utilization of concentrated sludge—particularly where manufactural wastes are present—within the range of practical consideration.

Messrs. Scott and McDowell.

MESSRS. R. D. SCOTT* AND R. F. McDOWELL† (by letter).—During recent years, and prior to 1909, the Scioto River, at and below Columbus, has been unsightly in appearance and foul smelling during low-water stages. This is what might have been expected, as at least one-half of the flow at such times was sewage.

As observed in January, 1909, the river bed was covered with a deposit of sludge from 1 to 12 in. deep. The appearance of the surface of the stream was marred by floating masses of sludge, and odor from the river was noticeable for a distance of at least 100 ft. from the banks.

TABLE 21.

	Scioto River, at storage dam.	Olentangy River, about 2 miles above the city.
Date	April 23d, 1909.	October 5th, 1909.
River elevation, in feet, above low water	2.8	0.0
Temperature of water, in degrees Fahrenheit	....	57.0
ANALYTICAL RESULTS, IN PARTS PER MILLION.		
Suspended matter	15.0	7.0
Oxygen consumed	7.0	5.0
Nitrites	0.013	Trace.
Nitrates	3.3	0.1
Organic nitrogen	....	0.3
Free ammonia	0.10	0.03
Chlorine	4.5	10.0
Dissolved oxygen	9.3	9.8
Bacteria (whole numbers)	6 000	30

During the summer and fall of 1909, about one-half of the raw sewage from that part of the city east of the river, was discharged directly into the river, owing to the cleaning of the intercepting sewer. For this reason, there was but little improvement over previous conditions during this time. Consequently, it will be impossible to show the effect of the purification of the sewage on the sanitary condition

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of the river under low-water, warm-weather conditions, until after the summer of 1910. Messrs. Scott and McDowell.

The composition of the water of the Scioto and Olentangy Rivers above the city, is indicated by the analyses given in Table 21.

The sanitary condition of the Scioto above the sewage works and at various stages during 1909, is shown by results of analyses of samples taken ½ mile above the outfall. These results are recorded in Table 22.

TABLE 22.

Date.	River stage, in feet above low water.	Analytical Results in Parts per Million.								
		Suspended matter.	Oxygen consumed.	Nitrogen as:				Chlorine.	Dissolved oxygen.	Bacteria, in millions per cubic centimeter.
				Nitrites.	Nitrates.	Organic nitrogen.	Free ammonia.			
Jan. 1, 1909	0.0	11	12	......	......	......	......	25	0.0	0.098
Jan. 8, 1909	0.0	18	9	......	......	......	......	27	0.5	0.220
Jan. 23, 1909	0.9	105	16	0.45	1.0	......	......	27	4.7	0.700
Feb. 6, 1909	1.1	74	23	0.50	0.7	......	......	18	7.2	0.400
Feb. 16, 1909	7.0	350	16	......	......	......	......	5	12.6	0.075
Mar. 5, 1909	3.2	174	11	1.14	5.8	......	......	4.5	12.2	0.008
Apr. 5, 1909	1.4	28	8	0.01	3.9	......	......	7.5	10.6	0.026
Apr. 16, 1909	1.8	32	8	0.014	4.0	......	......	6.5	9.8	0.017
Apr. 28, 1909	1.2	36	9	0.012	3.0	......	......	9.0	10.2	0.024
Sept. 20, 1909	0.0	25	14	Trace	0.2	2.3	4.3	....	0.0	2.350
Sept. 21, 1909	0.0	21	14	Trace	0.0	2.2	4.6	39.0	0.0	1.980
Sept. 29, 1909	0.0	26	14	Trace	0.1	2.5	5.9	47.0	0.0	0.480

The bad condition of the river, prior to February, 1909, as shown by the results recorded in Table 22, is explained by the fact that for the previous six months, the river had been at an extreme low-water stage, during about one-half of which time (before the sewage works began to operate) all the raw sewage was discharged into it. Between the beginning of this long-continued, low-water stage of the river and the starting of the sewage works, there had been no floods to scour out the river bed and free it of deposited and decomposing sludge. From June 1st, 1909, to the beginning of freezing weather, the intercepting sewer was being cleaned and raw sewage was discharged into the river. This latter fact accounts for its bad condition, as indicated by the September analyses.

The effluent from the sewage works is discharged at the west bank of the river and in a short distance becomes thoroughly mixed with the whole flow of the stream. This is shown by Table 23.

As stated, there has been as yet no favorable opportunity to study the Scioto under warm-weather, low-water conditions, but from March 5th to April 28th, 1909, a study of its sanitary condition was made. At this time only purified sewage was being discharged into the river. Samples were taken immediately above the plant and at several points

Messrs. Scott and McDowell.

TABLE 23.—Results of Determinations of Chlorine, in Parts per Million, in Samples of River Water, Showing the Mixing of the Effluent with the Water.

When River Elevation was 1.8 Ft. Above Low Water.*

	Source of Sample.			
	West bank.	West center.	East center.	East bank.
100 ft. below outfall	26.0	25.5	4.0	4.5
¼ mile " "	12.0	7.0	5.0	5.0
½ " " "	11.5	6.5	4.0	5.5
¾ " " "	10.5	6.5	6.0	5.0
1.0 mile " "	7.5	7.0	7.0	5.5
1¼ " " "	6.5	4.5	6.0	4.5
When River Elevation was 2.4 Ft. Above Low Water.†				
100 ft. below outfall	18.0	20.0	9.0	5.0
¼ mile " "	10.0	5.0	8.0	5.0
½ " " "	5.0	8.0	10.0	5.0
¾ " " "	5.0	6.0	5.0	5.0
1.0 mile " "	6.0	7.0	7.0	6.0
1¼ " " "	6.0	6.0	5.0	....

* Chlorine value for effluent at this time was 59 parts.
† Chlorine value for effluent at this time was 56 parts.

below it. The results of the analyses of these samples are recorded in Table 24. The river was from 1.4 to 2.6 ft. above the low-water stage at this time.

On October 6th, 1909, some analyses were made which show the self-purifying ability of the Scioto when low-water conditions prevail. These samples were taken during the time when the intercepting sewer was being cleaned, and when from 30 to 50% of the total flow of the raw sewage of the city was being discharged into the river. These results are recorded in Table 25.

The self-purification of streams has often been noted, but the improvement here is unusual for so short a distance. It is partly explained by the aerating effect of the many riffles in the first 6 miles below the plant.

A comparison of the composition of the river water just above the plant, at a time when the river was receiving about one-third of the raw sewage of the city, with the effluent from the plant, might be of interest. The results given in Table 26 are averages of samples, of both river water and effluent, taken on September 20th, 21st, and 29th, 1909. The river was at an extreme low-water stage at this time.

It is evident that in the future a very decided betterment of the sanitary condition of the river during warm-weather, low-water times may be expected. The effluent from the sewage works, itself non-putrescible 75% of the time, will be diluted at such times with approximately an equal volume of only slightly polluted river water.

Messrs. Scott and McDowell.

TABLE 24.

Sample No.	Analytical Results, in Parts per Million.							
	Suspended matter.	Oxygen consumed.	Nitrogen as: Nitrites.	Nitrogen as: Nitrates.	Nitrogen as: Free ammonia.	Chlorine.	Dissolved oxygen.	Bacteria, in millions per cubic centimeter.
1	32	8	0.012	3.6	0.21	7.7	10.2	0.0224
2	26	7	0.026	3.2	0.32	10.7	8.7	0.0345
3	29	9.5	0.037	3.2	0.40	10.7	8.6	0.0415
4	34	7	0.044	2.5	0.20	11.0	8.2	0.0135
5	23	7	0.035	3.0	0.11	9.5	8.6	0.0242
6	32	7	0.046	2.5	0.16	7.8	8.6	0.0092

Sample No. 1 = Average of four samples taken 0.5 miles above the outfall.
" No. 2 = " " " " " 3.9 " below " "
" No. 3 = " " three " " 6.75 " " " "
" No. 4 = " " two " " 11.3 " " " "
" No. 5 = " " one " " 17.5 " " " "
" No. 6 = " " three " " 25.0 " " " "

TABLE 25.

River.	Distance, in miles, from sewage works.	Temperature, in degrees, Fahrenheit.	Suspended matter.	Oxygen consumed.	Nitrogen as: Nitrites.	Nitrogen as: Nitrates.	Nitrogen as: Organic nitrogen.	Nitrogen as: Free ammonia.	Chlorine.	Dissolved oxygen.
Olentangy....	11.5 above	57	7	5	Trace	0.11	0.34	0.03	10	9.8
"	6.3 "	57	....	6	....	....	....	....	12	6.0
"	5.2 "	57	....	8	....	....	....	....	18.5	4.4
Scioto........	4.0 "	59	....	17	....	....	....	....	36.5	0.0
"	0.5 "	......	21	17	Trace	0.16	2.19	4.10	49.0	0.0
"	3.9 below	59	10.5	10.5	Trace	0.15	3.30	5.50	45.0	0.3
"	6.75 "	63	4.5	9.0	0.085	0.35	2.6	4.9	43.0	5.8

TABLE 26.

	Analytical Results, in Parts per Million. River water.	Analytical Results, in Parts per Million. Effluent from sewage works.
Suspended matter..	24.0	26.0
Oxygen consumed..	14.0	15.0
Nitrites and nitrates..	0.1	3.7
Chlorine..	43.0	70.0
Dissolved oxygen..	0.0	4.3
Bacteria (millions per cubic centimeter)....................	1.60	1.63
Days required to decolorize 1 cu. cm. of a 0.1% solution of methylene blue per 250 cu. cm. of sample when incubated at 37° cent....................................	0.23	4.5

Mr. Wagner. SAMUEL TOBIAS WAGNER, M. AM. SOC. C. E. (by letter).—It is unique, in the presentation of papers to this Society, that there should be combined in one paper the description of a plant for the purification of the water of a municipality for domestic purposes and, at the same time, a description of a method for the treatment of its sewage. This paper is specially interesting on account of the fact that it treats both subjects comprehensively, and describes not only the construction with great detail, but also the operation for a period sufficient to show the results which may be expected when everything has got a bearing and is running in a regular manner. An item of great value is the detailed supervision of the costs. Such detail is unusual in work of this magnitude, as it is difficult to separate it without much painstaking, and the author is to be congratulated not only for its admirable arrangement but also for the presentation of the whole subject in such a logical and complete manner. It is the duty of every engineer to emulate such an example, and to prepare and present papers on the work under his charge as promptly after completion as has been done in this case.

Under the head of "Pumping Station," the author alludes to the fact that the ordinary cut stone used in the trimming of buildings of this class was replaced with concrete constructed in special moulds and with carefully finished surfaces. Architectural treatment of this kind is of special interest at this time when concrete is being used to so great an extent, and the writer would like to see a photograph of at least a portion of this building, showing the appearance of the parts thus treated as well as one or two details. As gleaned from the description, the general effect must be very satisfactory.

The problem of purifying a water of the character described, by softening and then by mechanical filtration, is unusual and very interesting. Apparently, no preliminary investigations on an experimental scale were made to determine the best methods for its treatment. If no such experiments were made, great credit is to be given for the design of the details of the plant, as the combinations and rapid variations in the amounts of "total hardness" and "turbidity," given in the tables covering the period of operation, are indicative of the care taken to secure satisfactory effluents. The writer does not recall any published data dealing with a water of such a character. The tables relating to the operation of the filters from January to August, 1909, show that the results are steadily improving as experience with the water increases, and any data of later operations which may be given by those in charge of the plant will be of great interest as indicating the effect of this treatment on the water.

It is not surprising that detailed experiments were made on the sewage to be treated, not only because of the fact that it was desirable to obtain all the data possible as to its peculiarities before proceeding too

far with the design, but also because at the time the plant was projected the general question of sewage treatment in the United States on such a large scale was in its infancy. Great credit is due to the city authorities for permission to spend the money necessary for these experiments, and it is now possible for them to see the wisdom of their action. The problem of sewage treatment of large cities in the United States is undoubtedly one of the most vital sanitary questions, and, in the very near future, it is certain that many municipalities will be compelled to spend enormous sums of money for such improvements. Such a complete description of this work at the present time, therefore, is most opportune and valuable. Mr. Wagner.

From an examination of the tables of costs, it would appear that Columbus has now completed a large municipal work of excellent design and at a very reasonable cost.

J. CORBETT, ESQ.* (by letter).—This work seems to be remarkably bold and complete to have been carried out in so short a time, and there is no doubt that it will prove eminently beneficial to Columbus. Mr. Corbett.

The Scioto River Storage Dam is of such ample section that it cannot, in all human probability, cause any risk to the great city below it.

The water-softening and filtering arrangements seem to be very efficient in actual working; but, without the evidence given in Table 12, the writer would have thought it impossible to work the fine sand filters at the rate of 120 000 000 gal. per acre per day, as stated. This rate is far greater than any of which he has record, except for coarse-sand preliminary filters. The cleansing of the filter by water and air seems to be very simply and effectively arranged, and no doubt accounts for the wonderful rate of working.

Turning to "The Improved Sewage Works," some of the best features of the works at Birmingham and at Salford seem to have been selected, but it may yet be found expedient to add some sort of straining filter between the septic tanks and the bacteria beds. Experience at Salford has shown that these beds gradually become choked with the solid matters passing on to them, even when, as at Birmingham and Columbus, the medium averages more than 1 in. in diameter. There is space enough, however, for such an addition, if found requisite.

The hexagon plan for the bacterial filters, with its central gate-house, etc., seems to be an excellent arrangement, but no mention is made of provision for a fall from the center to the circumference, in order to equalize the pressure on the spray jets. The writer has found a fall of 1 in 250 for a whole structure very efficient.

The spray jets used at Columbus are of the type preferred by the writer for septic effluent, because having only one hole, they are less likely to choke; their fault of throwing the drops in a ring, however,

* Borough Engr., Salford, England.

Mr. Corbett. needs the corrective proposed, that is, an automatic variation of the head. The writer used this type on experimental filters from 1893 to 1898, but, on the permanent beds, substituted the well-known two-hole jets, and, later, some with six internal holes. These give no trouble with the sewage liquor which has passed through the coarse-sand roughing filters.

The normal rate of working the filters at Columbus, 2 000 000 gal. per acre per day, is the same as that used at Salford, with ¼ in. to 1 in. medium, with double this rate during wet weather. The writer is not aware of any coarse-grained filters, like those at Columbus, which treat English sewage efficiently at this rate; but no doubt this rate may be used in treating the more dilute sewage at Columbus.

In a few years the filter beds will probably become clogged to such an extent that the whole medium will require to be dug out and washed; but as there is an ample water supply, this may not be a very costly renovation.

As to the aeration of the filter beds, the writer is of the opinion, though he cannot quote any actual facts in its support, that the beds would be improved by some ample air pipes carried down to the collecting channels, so as to provide for a current vertically through the medium.

It is to be hoped that there may soon be an opportunity to abandon the disposal of the sludge into the river during freshets. It seems to imply either a very irregular cleansing of the settling basins and septic tanks, or a certain laxity in the definition of freshets in the river.

Looking to the whole work of water supply and sewage disposal, the writer heartily congratulates the author on its evident efficiency, and on the considerable ingenuity and originality shown in many of its details.

Mr. Copeland. W. R. Copeland, Assoc. Am. Soc. C. E. (by letter).—Mr. Gregory refers to the fact that the underlying rock of the Scioto River watershed is limestone. It may be described more correctly as a dolomite, or a mixture of lime and magnesium carbonates, combined with sulphates and chlorides of the same bases. These salts make the water hard, and therefore the water-softening process is one of the most important features of the Columbus water purification works.

In softening the water "quick" or "fresh-burned" lime is used to remove the carbonates and magnesium salts, and "soda ash" or "carbonate" of soda to remove the sulphates and chlorides. Lime has been used for years to remove carbonates from municipal water supplies, but Columbus is the first city to undertake to remove the sulphates and chlorides by soda ash on a scale as large as 30 000 000 gal. in 24 hours. Moreover, the presence of magnesium makes the problem more complicated than in many purification works, and its

removal has not ordinarily been attempted in city water-softening plants heretofore. Mr. Copeland.

The results obtained at Columbus demonstrate that the magnesium, the sulphates, and the carbonates can be removed without difficulty at all seasons of the year, provided the softening chemicals are applied properly and the operation of the plant is watched by trained men.

As the bed-rock of the water-shed is dolomite, the ground-waters or waters which work into the river during dry seasons are heavily charged with salts which make the water hard. In wet seasons the conditions are reversed, and the river contains large volumes of soft surface water, carrying mud scoured from the cultivated fields, bacteria washed from sewers and barn yards or fields, and vegetable coloring matter from woods and swamps. It is evident, therefore, that the river water changes in character markedly, and these changes take place more rapidly, perhaps, than in any other municipal plant where water softening combined with purification is conducted on such a large scale.

These conditions arise partly from the fact that a current flows through the storage dam continuously, and so rapidly in a flood that the total volume may be displaced two or three times in 24 hours. In other large cities the water supplies are equipped with great settling basins which store the raw water for several hours or even days if muddy, and equalize the fluctuations, but the Columbus plant must take whatever is flowing in the river—hard or soft, and clear or turbid water.

Through the courtesy of the superintendents of the plants at Cincinnati and New Orleans, data obtained in those cities during 1909, are presented in Table 27 for comparison with those from Columbus.

Recognizing the fact that conditions change in the river water through a wide range, the designing engineers built many devices at Columbus for making the application of chemicals to the water elastic. Even so, however, experience has shown that the adjustments in the regulating apparatus were not sufficiently extensive to cope with the variations in composition of the river water. In addition to this, the lime varies in composition, and often carries from 10 to 20% of "foreign" matter, consisting of "unburned" rock, cinders, bricks, etc. All such stuff had to be carried away in buckets at first, as the drain pipes leading from the slaking and solution tanks were too small, but since they have been replaced by 3 and 4-in. drain pipes it is an easy matter to wash them out to the river.

Fine-mesh screens of large area have also been placed over the outlet pipes leading to the chemical feed regulators, and extra stirring arms have been attached to the agitators in the solution tanks in order to keep the suspended matter from settling.

Mr. Copeland.

TABLE 27.—COMPARATIVE DATA AT CINCINNATI, NEW ORLEANS, AND COLUMBUS.

All in parts per million.

CINCINNATI—1909.

	River Water.			Settled (Coagulated) Water.			Filtered Water.		
	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Total alkalinity	95	21	46.2	78	30	51.1	74	27	49
Incrustants	79	7	28.2	......	......	......	72	8	36.7
Turbidity	2 000	15	225	68	12	23	0	0	0
Number of bacteria per cubic centimeter	132 000	80	9 300	11 500	10	475	800	0	75

NEW ORLEANS—1909.

	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Total alkalinity	180	60	95	115	29	49	84	27	46
Incrustants	160	10	25	......	......	......	......	......	33
Turbidity	2 500	50	600	250	2	38	3	0	0
Number of bacteria per cubic centimeter	10 000	500	2 000	1 100	20	200	400	2	26

COLUMBUS—OCTOBER 1ST, 1908, TO SEPTEMBER 31ST, 1909.

	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Total alkalinity	250	50	162	106	23	54	98	3	43
Incrustants	287	11	108	118	12	51	87	11	50
Turbidity	1 500	4	76	104	0	13	4	0	0
Number of bacteria per cubic centimeter	125 000	25	7 100	50 000	0	680	5 850	0	145

Designing engineers will do well to note that wherever sludge finds a chance to lodge, as in elbows, valves, measuring devices, etc., sediment accumulates, rapidly shutting off the flow, and interfering with the application of chemicals. Such deposits cause frequent and annoying interruptions of the lime feed at Columbus, requiring a laborer to flush them out at frequent intervals.

The soda and coagulant solutions do not carry débris in such large quantities nor of the same character, but, as these chemicals are sometimes shipped in jute or burlap sacks, the fine hairs rubbing from the cloth form mats over the screens. To correct these conditions, removable screens have been installed at the outlets of the dissolving tanks, and "constant head" boxes in front of the orifices.

In addition to the interruptions of flow caused by these "foreign" impurities, the lime, soda, and sulphate of iron solutions form calcareous, crystalline, and scaly deposits which choke the delivery pipes in a short time unless flushed frequently by jets of water under pressure. For example the 8-in. cast-iron pipes, which deliver a mixture of lime liquor and raw water at four points in the saturators, become filled, in a 2-weeks run, with granular accretions of calcium carbonate

Mr. Copeland.

to such an extent that one could not run a 2-in. pipe through the opening left. The bore of the "lead-lined" coagulant pipe in the gate-house is reduced by flakes of iron rust from 3 in. to ½ in. in many places. This pipe is laid for part of the way in concrete and is submerged in water during the ordinary course of work, thus making these accumulations in the coagulant lines especially serious, because the piping is inaccessible for cleaning.

All such important apparatus should be placed in open areas which are easy of access, and should be provided with plenty of flange unions so that the pipes can be taken apart for cleaning.

The coagulant solutions have eaten the steel pipes wherever the lead lining is broken—as at joints between valves and fittings—and it seems as though it would be advantageous to make long stretches of coagulant lines of cast iron.

Lime solutions are not corrosive in themselves, but the suspended particles carried by the milk of lime, flowing through the "chemical feed regulator," cuts the edges of the orifice plates, screens, and valve seats. The soda solution attacks concrete, dissolving out the calcium sulphate and leaving the sand and gravel, which makes the walls of the concrete tanks rough.

The acid carried by the sulphate of iron and alumina solutions dissolves the carbonates out of the concrete tanks, eats the iron pins out of the valves, and, in fact, is destructive to almost all metals except lead, though brass pipe stands well.

After passing the chemical feed regulator, the lime liquor mixes with 60% of raw water and enters the saturators. According to the original design, from 15 to 25% of raw water was to have been diverted through the saturators to make clear saturated lime-water containing 60 grains of CaO per gallon. Soon after starting the plant, however, this method of procedure was changed because the lime liquor rose in restricted areas and the effluent from the saturators rarely carried more than 45% of CaO.

Finding that the original plan was not efficient, additional paddles were attached to the rotary stirring shafts, and larger volumes of raw water were forced into the saturators. By this procedure more magnesium is precipitated, because larger volumes of raw water come into contact with the lime while it is still caustic—a condition which is necessary for converting the soluble bicarbonate into the insoluble hydrate. This hydrate, together with some precipitated carbonate of lime, forms a sediment in the liquor flowing from the saturators. The particles of suspended matter serve as nuclei on which the water-softening precipitates, which develop in the reaction chambers, may collect. The sludge formed by the precipitates, together with the coagulated mud, collects for the most part in the first sections of Settling Basins 1 and 2. This deposit has a soft jelly-like consist-

Mr. Copeland. ency, forming, in 3 or 4 weeks, a mass from 12 to 15 ft. deep near the inlet ends of the eastern compartments of Basins 1 and 2. The depth of the sludge falls off rapidly to 4 or 5 ft. at the outlet ends of these basins, and sediment to a depth of only about 3 or 4 ft. collects in the other basins during the year. When a basin is to be cleaned, the inlet and outlet water-gates are closed, and the valves on the drains in the floor of the basin are opened, allowing the sludge to escape to the river. Most of the sludge will run out in this manner, and what remains is flushed out readily with a 2½-in. fire stream. By using hose, six men clean a basin in from 3 to 4 hours.

Attention is called to the fact that the settling basins remove most of the chemical precipitates, mud, and bacteria. In fact, it is necessary that from 80 to 90% of such materials should be taken out there in order to obtain a pure clear effluent from the plant. In order to secure this result, provision was made originally for applying coagulant at the entrance to each or any set of basins, at the outlet of the last basins, and in the settled-water channel on the way to the filters; but experience has shown that better efficiency is obtained by adding most of the coagulant to the raw water as it enters the plant, and a small additional dose to the settled water as it passes to the filters. There are two reasons for this. In the first place, by adding coagulant to the raw water at the inlet the whole body of water becomes charged and is in such a condition that when the caustic lime strikes it the coagulant precipitates in large flocks.

Unfortunately, however, certain species of bacteria grow, at some seasons, in the sludge deposited in the mixing chambers, conduits, and settling basins. Moreover, the water-softening reactions require several hours to become complete, and, as the precipitate of calcium carbonate is very fine, a secondary turbidity sometimes develops in the settling basins.

These bacterial growths and the turbidity resulting from the water-softening reactions constitute a second reason for adding a dose of coagulant at the outlet of the settling basins to form a mat on the surface of the filters for removing the last traces of suspended matter and bacteria. When the sediment is coarse and heavy—for instance, in the early stages of a flood—a comparatively small amount of coagulant will clarify the water, but, toward the end of the flood, when the particles of sediment become fine and the coloring matter from the swamps and fields increases, coagulants do not react with their usual efficiency.

It becomes necessary at such times to add a slight excess of lime so that the effluent from the mixing tanks shall have from 10 to 15 parts per million of caustic alkalinity. Laboratory experiments indicate that this excess of caustic is required to replace the alkaline bicarbonate of lime removed by the water-softening process and to coagulate the finely-divided particles of suspended matter which re-

main. As there are only a few days in the year when lime is not required for softening, it would not be possible to cut the lime out for any considérable number of days in succession. Therefore, at Columbus it is not possible to depend on the bicarbonates, which are carried naturally in the water, to precipitate the coagulant. The treated water always carries a considerable quantity of monocarbonate of lime, but this alkaline salt does not seem to react with sulphate of iron or alumina in the same manner as bicarbonate or caustic lime. Mr. Copeland.

A glance at the tables in the paper will show that large quantities of coagulant were used occasionally. These applications were made in order to remove the bacteria which grew in the sludge, and as the treatment did not prove to be wholly satisfactory, hypochlorite of lime is being used at present to increase the bacterial efficiency and for the purpose of economy.

When the settled water applied to the filters has a turbidity of less than 25 parts per million and contains a little coagulant, the sand beds remove the suspended matter without difficulty. During the early part of 1909, however, the gravel underdrains were deranged, and the sand grains became coated to some extent with deposits of lime and iron, making it necessary to coagulate the turbidity in the settled water with extra alum.

From August to December, 1908, compressed air was applied to the beds of sand during the process of washing, but as the current of wash-water applied seems to clean the beds sufficiently, the treatment with compressed air has been discontinued.

The designing engineers expected that the filters would be washed with a current of water having a maximum upward velocity of 10 in. per min. The actual rate does not exceed 6 or 8 in., however, and the velocity is as great as can be used without lifting the sand into the gutters. It is possible, also, that screens would have to be placed over the under-drains, or deeper layers of large-sized stone laid on top of the strainers to prevent the gravel from being dislodged, if the current of wash-water should be applied at a higher rate.

The writer desires to add a word of praise for Mr. Gregory and the engineers who assisted him in designing and building the plant. They had very little knowledge of the character of the Scioto River water to guide them, and the data in regard to the best method of treatment for softening the water were gained from a series of laboratory tests carried out with small volumes of water for a period of only 2 or 3 months.

The plant has handled the water successfully, the typhoid fever rate has been reduced, the people have abandonded their cisterns, and the water gives general satisfaction for boiler purposes.

On account of the "flashy" character of the river water, however, the plant requires constant watching, and for that reason the bills for superintendence and labor have been high.

Mr. Sperry.

W. A. SPERRY, Esq.* (by letter).—It may not be amiss to mention the problem confronting those having the water purification works in charge in finding a supply of lime of sufficient purity and within a distance such that the freight charges would not prohibit its use.

Something of the importance of this problem may be realized when it is remembered that during a period of 13 months the average daily consumption of lime was 9.2 tons; the average total hardness of the Scioto River for the same period was 270 parts per million, 60% of which required lime treatment; the magnesium averaged 23.4 parts per million, and required an extra lime treatment.

Experience gained at this plant has shown that those limes which contain less than 1% of magnesium, and 90% or more of calcium oxide (CaO) are most economical and give the most efficient and reliable results, and that local limes are sufficiently high in silica, alumina, iron, and especially in magnesium, to reduce the percentage of available calcium oxide to less than 80. It should be said, further, that it has rarely been possible to obtain limes delivered at the plant with more than 88% of available calcium oxide, the low percentage being chargeable to weather conditions, distance hauled, and the much more rapid loss of available calcium oxide by the fine particles than the larger sizes in a body crushed lime, there being a loss of from 2 to 5% of available calcium oxide from these causes during transit from the point of shipment.

Table 28 shows the average analysis of the limes furnished by different companies, representing limes from Ohio, West Virginia, Maryland, and Pennsylvania.

TABLE 28.—ANALYSES OF LIMES.

Company.	CaO.	Total CaO.	Total Mg.	Matter not water-soluble.
A	77.4%	59.42%	6.18%	21.6%
B	79.4%	60.82%	5.58%	18.5%
C	82.5%	......	......	......
D	86.6%	66.12%	0.64%	13.4%
E	87.9%	......	trace	......
F	87.7%	......	......	......
G	88.0%	66.36%	1.62%	......

The chief source of loss of calcium oxide is by the absorption of carbonic acid gas from the atmosphere, that is, carbonation, and seems to be due to the three causes just mentioned. One of the specifications under which lime is furnished to the plant calls for a lime crushed to a size not greater than 2½ in. in any dimension. It is received in bulk in tight box cars and is sacked at the plant.

* Asst. Chemist, Columbus Water Purification Works.

Tables 29 and 30 are of interest as showing the relative loss of available calcium oxide in the various sizes of this crushed lime when separated by standard-mesh sieves. In each case cited in the tables about 100-lb. of the lime representing the "run of the car" was separated by sieves of $\frac{1}{16}$- to 1-in. mesh, each size thus separated being weighed and sampled for chemical analysis. Mr. Sperry.

TABLE 29.

Car No. 1	Lime retained by 1-in. mesh	6.9%	86.2% CaO
	" passing 1-in. mesh, retained by $\frac{1}{2}$-in. mesh	33.8%	85.6% "
	" " $\frac{1}{2}$-in. " " " $\frac{1}{4}$-in. "	19.2%	84.1% "
	" " $\frac{1}{4}$-in. " " " $\frac{1}{8}$-in. "	14.3%	85.1% "
	" " $\frac{1}{8}$-in. " " " $\frac{1}{16}$-in. "	7.3%	82.5% "
	" " $\frac{1}{16}$-in. "	18.5%	82.5% "
	Analysis of average sample		85.2% "
Car No. 2	Lime retained by 1-in. mesh	7.3%	85.2% CaO
	" passing 1-in. mesh, retained by $\frac{1}{2}$-in. mesh	37.8%	80.7% "
	" " $\frac{1}{2}$-in. " " " $\frac{1}{4}$-in. "	18.1%	80.9% "
	" " $\frac{1}{4}$-in. " " " $\frac{1}{8}$-in. "	10.8%	80.3% "
	" " $\frac{1}{8}$-in. " " " $\frac{1}{16}$-in. "	5.4%	79.6% "
	" " $\frac{1}{16}$-in. "	20.6%	72.2% "
	Analysis of average sample		79.6% "

TABLE 30.

	Car No. 1.	Car No. 2.
Percentage of available calcium oxide, in cars as received	89.1%	85.5%
Percentage of available calcium oxide, in cars at time of making mechanical analysis	85.2%	79.8%
Number of days elapsing between the receipt of the lime and the mechanical analysis	4	16
Loss of available calcium oxide from standing	3.9%	5.7%
Variation shown between lime obtained by a 1-in. mesh sieve and that passing a $\frac{1}{16}$-in. mesh sieve	3.7%	13.0%

With respect to the relative extent of loss of CaO due to the absorption of CO_2 and hydration of lime in storage, the curves in Fig. 18 are of interest. They are the results of a series of laboratory experiments extending over a period of a month or more. A number of 1-gramme samples of lime, ground to pass a 100-mesh sieve, were exposed to the action of the atmosphere in the lime storehouse in a box covered with a cloth in such a way as to give free access of air but to protect them from dust, etc. One of these samples was analyzed each day, note being taken of all atmospheric conditions as shown. Attention is called to the marked similarity of the lime curves after the seventh day.

At the end of 26 days a series of chemical analyses was made on the samples remaining to determine as nearly as possible the character of the changes that had taken place. It was found:

That the total loss of available calcium oxide amounted to about 19%;

Mr. Sperry.

That direct determinations as to the extent of the carbonation by widely differing methods accounted for all but from 1 to 2% of this loss, and, therefore, indicate that the loss of available calcium oxide is largely rue to carbonation;

That the hygroscopic moisture, as determined by the drying test, amounted to from 1.5 to 2.0%;

That, after a time, the loss of available calcium oxide ceases, the lime remaining of the same strength, with slight fluctuations, protected by an outer coating of hydrated and carbonated material;

That the hydration that may take place does not seem to destroy the value of the lime as a water-softening agent; and

That the lime as shipped carries about 1% of unburned stone and about 3% of calcium in a form other than calcium oxide.

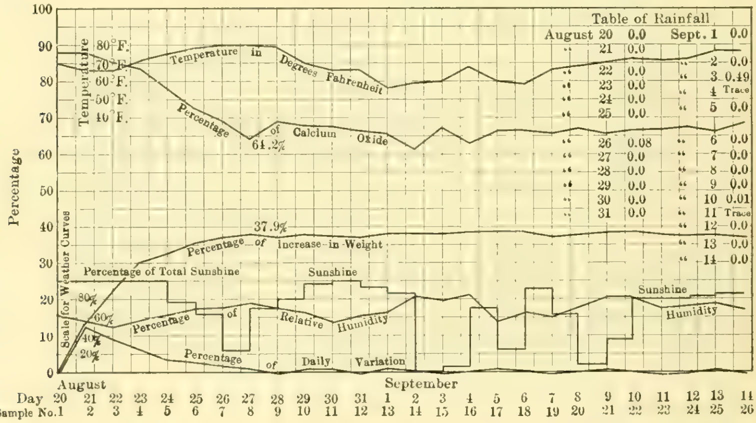

FIG. 18.

Mr. Sole.

J. W. SOLE, ESQ.* (by letter).—The Columbus water purification plant started operation in September, 1908. Some months later the city meter inspectors noticed that a number of meters were not registering the flow of water correctly. On examination the meters were found to be clogged with a slimy white deposit which interfered with the rotation of the discs. Later, the trouble subsided to some extent, but seemed to be of sufficient importance to warrant a special investigation.

During the summer of 1909 a series of studies was made for the purpose of discovering the extent and nature of the action of the water on metals. At the same time, several proposed remedies were tested. A brief explanation of the water-softening process in use at the plant may help to a clearer understanding of the experiments which follow.

* Asst. Chemist, Columbus Water Purification Works.

The chemicals used in the softening and purification of the Scioto River water at Columbus are lime, soda ash, and sulphate of alumina or sulphate of iron. The purpose of the lime is to absorb the excess of carbonic acid gas which holds the carbonate of lime and magnesium in solution in the river water and at the same time to remove free carbonic acid gas, if present. When the reaction takes place the newly formed carbonate of lime, together with the carbonate of lime liberated by the removal of the carbonic acid gas, is largely precipitated. It is necessary to make a further addition of lime to convert the magnesium (now in the form of a normal carbonate, which is a more soluble salt than the corresponding carbonate of lime) to the insoluble hydrate. Although, for most purposes, the carbonates of lime and magnesia may be considered insoluble, yet in the excessively dilute condition which is maintained in a water-softening plant they are soluble to the extent of about 40 parts per million. Mr. Sole.

The soda ash is added to precipitate the other soluble salts of lime and magnesia, namely, the sulphates, chlorides, and nitrates of these metals, as normal carbonates of lime and magnesia. At the same time there are formed, and remain in the water, sodium sulphate, chloride, and nitrate, but the presence of these salts is not objectionable.

The general method of procedure in the experimental work was to expose metals of known weight and surface area to the action of chemically treated water of known composition for definite lengths of time. In this way quantitative results were secured.

The metals chosen were lead, zinc, galvanized iron, and black iron. Zinc pipes are not used, but a zinc coating on a black-iron pipe is in common usage. Other than this, the metals selected are those used for water pipes.

It was learned quickly that sheet lead is unaffected, beyond tarnishing and a slight gain in weight due to surface oxidation. After the film of oxide covered the surface, there was either no increase in weight or the rate of increase was greatly diminished. Lead, therefore, was not included in all the experiments.

In order to learn something of the rate of deposition and to secure sufficient deposit for analysis the following experiment was made: Two glass cells were set up, each having a capacity of 11 liters. These were filled, respectively, with zinc and galvanized-iron plates separated by rubber stoppers. Water having the average composition shown in Table 31, taken from analyses made every 8 hours, was then passed into the bottom of the cells and carried off the surface by a suction arrangement.

It will be noticed from the analyses in Table 33 that the deposits recovered from the zinc plates are similar in composition to those from the galvanized-iron plates, with one exception, the deposit on

Mr. Sole.

TABLE 31.—AVERAGE COMPOSITION OF THE WATER, IN PARTS PER MILLION.

Total alkalinity	46	Total hardness	111
Phenol alkalinity	15	Turbidity	0
Caustic alkalinity	0	Color	3
Incrustants	64	Magnesium	15

Table 32 shows the details of the experiment.

TABLE 32.

Metals used.	Extent of surface of metals exposed.	Time of exposure to action of water.	Quantity of water passed over plates.	Amount of deposit recovered.
Zinc	5 000 sq. cm.	2 weeks	1 000 gal.	4.11 grams.
Galvanized iron	5 000 "	2 "	1 000 "	4.06 "

The analyses of the deposit recovered is given in Table 33.

TABLE 33.

	Zinc plates.	Galvanized-iron plates.
Zinc	42.58%	41.30%
Magnesium	2.14	1.63
Calcium	trace	trace
Iron	none	trace
Sodium	trace	trace
CO_3 radical	48.02	47.72
SO_4 radical	5.80	8.10
	98.54	98.72

the galvanized iron containing a trace of iron, is absent in the zinc plate deposits.

It appeared that the normal carbonates in the water might be responsible for the action, as the chief constituent in the deposits was zinc carbonate. If such were the case, distilled water having normal carbonates in solution should give deposits on metals. To test this a 50-gal. barrel was steamed out and fitted with a stirring device, which was attached to a small motor. The barrel was filled with distilled water, treated with an excess of freshly precipitated calcium carbonate, which was carried into solution by the carbonic acid gas present. The calculated quantity of lime-water was then added, giving a water with 20 parts of normal carbonate of lime. After settling, the clear water was siphoned through two 500-cu. cm. bottles containing, respectively, zinc and galvanized-iron plates, each having a surface of 75 sq. cm.

The bottles were fitted with two-holed rubber stoppers, the water passing to the bottom of the bottle and out through a bent glass tube with one arm longer than the other. The rate of outflow was controlled by a pinch-cock, and amounted to 1 gal. per hour per bottle. This apparatus was used in many of the succeeding experiments. Mr. Sole.

Deposits appeared on the surface of each metal, and a relatively large amount was deposited in the bottoms of the bottles.

In this experiment, as well as in succeeding ones of this type, the metals were weighed before and after exposure to the action of the water. The character of the deposit was such, however, that more light was thrown on the relative amount by observation while the bottles were filled with water. After removing the metals and filtering the deposits in the bottom of the bottles, the total deposition on a given metal plate was seldom more than 0.01 gramme, and usually varied from 0.001 to 0.005 gramme.

The same procedure was observed with distilled water treated with normal carbonate of magnesium. To obtain a saturated solution of magnesium carbonate, it was necessary to treat the distilled water with an excess of finely pulverized magnesium carbonate, pass carbonic acid gas into the water during agitation, and finally boil the water. Water (50 gal.) treated thus with magnesium carbonate was boiled for ½ hour in liter flasks, and the resulting water, containing 30 parts per million of normal carbonate of magnesium, was passed over metals. Deposits appeared both on the metals and in the bottles, but not in as large quantities as in the case of the water treated with lime carbonate.

To discover whether dissolved oxygen might not contribute to the bad result, an experiment was made as follows: Two carboys, filled with 25 gal. of distilled water, were connected in circuit, and air, previously freed from carbonic acid gas, was bubbled through the water for 24 hours. At the end of this period, the aerated carbon-dioxide-free water was passed over zinc and galvanized-iron plates as usual. The surfaces of both metals were covered with deposit and the bottoms of the bottles contained sediment.

The zinc plates, weighing 30.6754 mg., increased 6 mg. in weight, while the galvanized-iron plates, weighing 27.9458 mg., increased 3.2 mg.

The increase in weight may be accounted for by a combination of the metal with the oxygen carried into the water in the form of air, and with normal carbonates which remained dissolved in the water after the lime and soda treatment.

At this point the action on metals of a softened water containing varying amounts of caustic was taken up, 50 gal. of raw river water being treated with an amount of lime and soda calculated from the analyses to give a water comparable to the filtered water leaving the

Mr. Sole. plant at that time, the difference being in the amount of caustic present in the specially prepared water. Three experiments were made, the caustic present being, respectively, about 5, 15, and 20 parts per million, calculated as carbonate of lime. The same procedure was observed in each experiment, as follows: The quantity of raw water treated was 50 gal., and 60% of this was treated with lime cream of a known strength, in amount sufficient to give the caustic desired in 100% of the water. After agitation for 1 hour in the barrel, the remaining 40% of raw water was added, followed by agitation for 15 min. Sodium carbonate in solution was then introduced into the water followed by thorough mixing for an hour. After complete clarification by settling, the water was siphoned over lead, zinc, galvanized-iron, and black-iron plates, as usual. Side by side, a duplicate apparatus was set up and tap water was passed over similar plates for the same length of time, and in equal amounts. At the end of the experiment the metal plates were removed, dried carefully, and examined for relative amounts of deposit. The weights of the metals were taken before and after exposure to the water. The analyses of the water are given in Table 34.

TABLE 34.

Experiment No.		Total alkalinity.	Phenol alkalinity.	Caustic alkalinity.
I	City water	40	14	0
	Specially prepared water	37	21	5
II	City water	36	17	0
	Specially prepared water	43	29	15
III	City water	35	16	0
	Specially prepared water	42	30	18

The lead plates in all cases increased slightly in weight, namely, 0.5 to 2.0 mg., on plates weighing about 15 grammes, but no trace of deposit was formed.

The zinc plates had a larger increase in weight when city water was used, the difference amounting to about 1 mg. on deposits weighing from 2 to 3 mg.

The galvanized-iron plates lost weight, the loss being smaller with the use of city water. This difference varied from 0.0 to 2.0 mg. on total losses of 0.8 to 4.0 mg.

The black-iron plates increased in weight from 1.5 to 6.5 mg. with city water, and lost 1.0 mg. in weight with the water containing caustic.

The inference from these experiments is that water containing caustic, in the amounts used in the experiments, does not contribute to a larger deposit than when no caustic is present.

An experiment was next made to discover whether the sodium carbonate treatment affected the deposit appreciably. A quantity of river water (50 gal.) was treated with lime cream, thoroughly agitated and settled, and the clear water was siphoned over weighed metals. At the same time city water, softened by both lime and soda, was run in duplicate apparatus, the conditions being kept similar in every way. The analyses are given in Table 35. Mr. Sole.

TABLE 35.

	Chemical added.	Total alkalinity.	Phenol alkalinity.	Caustic alkalinity.
River water	None	173	0	0
City water	Lime and soda	41	13	0
Specially prepared water	Lime only.	27	11	0

With the exception of the lead, deposits appeared on the metals and in the bottles, quite the same in the case of the water softened by lime and soda as in the water softened by lime only.

As the deposit obtained in the first experiment contained a large amount of carbonate, it was thought that any treatment of the water which would reduce the normal carbonates would effect good results. A powder, which proved to be sodium bicarbonate, called "American Carbonating Powder," was made the basis of many experiments, and sodium bicarbonate, likewise, was carried through similar tests. Preliminary experiments were made to see if the normal carbonates in the water were reduced by the use of these two chemicals, through liberation of carbonic acid gas. A typical experiment using each chemical is given here. This is corroborated by many others.

The conditions of the experiment were as follows: Nine ½-gal. bottles were filled with 3 liters of river water. Each bottle was then treated with a saturated solution of lime-water at the rate of 4¾ grains of calcium oxide per gallon. The bottles were then shaken for an hour, and then the soda, in soluble form, was added. The shaking was then repeated for an hour. After 24 hours standing, the supernatant liquid was siphoned through filters and analyzed. Erythrosine was used as an indicator in securing the total alkalinities. The details are given in Table 36.

It will be noticed from Table 36, that there is a reduction in normal carbonates, and to practically the same extent with both the use of the "American Carbonating Powder" and the sodium bicarbonate.

To discover whether this reduction in normal carbonates might affect deposits on metals, many experiments were made of which the following is an example. The conditions of the experiment were as follows: A quantity of river water (50 gal.) was treated with lime

Mr. Sole.

TABLE 36.—REDUCTION OF NORMAL CARBONATES, IN PARTS PER MILLION.

No. of sample.	CaO, in grains per gallon.	"American Carbonating Powder," in grains per gallon.	Sodium bicarbonate, in grains per gallon.	Total alkalinity.	Phenol alkalinity.	Caustic alkalinity.	Normal carbonates.	Maximum reduction of normal carbonates.
River water	0	0	0	140	0	0	0	....
1	4¾	0	0	50	23	0	46	....
2	4¾	1	0	48	15	0	30	....
3	4¾	2	0	56	15	0	30	....
4	4¾	3	0	61	13	0	26	20
5	4¾	4	0	70	14	0	28	....
6	4¾	0	1	49	15	0	30	....
7	4¾	0	2	57	15	0	30	....
8	4¾	0	3	62	14	0	28	....
9	4¾	0	4	67	12	0	24	22

cream of known strength, and agitated in the barrel by the stirring device for 1 hour. Sodium bicarbonate in solution was then added in amount sufficient to give a water with a total hardness of about 100 parts per million calculated to carbonate of lime. This was followed by agitation for an hour, and, after settling for 24 hours, the clear water was siphoned over weighed metals as usual. At the same time a duplicate experiment was run using tap water. The analyses are given in Table 37.

TABLE 37.

Kind of water.	Gallons of water used.	CaO added, in grains per gallon.	Na_2CO_3 added, in grains per gallon.	$NaHCO_3$ added, in grains per gallon.	Total alkalinity, in parts per million.	Phenol alkalinity, in parts per million.	Normal carbonates, in parts per million.	Incrustants, in parts per million.	Mg, in parts per million.
City water	50	5.9	0.2	0	41	14	28	54	12.9
Specially treated water.	50	6.25	0	2.3	67	3	6	56	16.3

The weights of the deposits formed are given in Table 38.

TABLE 38.

	Lead (no deposit) increase in weight, in milligrammes.	Zinc, in milligrammes.	Black iron, in milligrammes.	Galvanized iron, in milligrammes.
City water	0.4	7.8	9.0	8.4
Specially treated water	2.6	4.4	10.4	3.2

Mr. Sole.

The lead in both cases increased somewhat in weight, but no deposit formed. The appearance of the deposits indicated a greater difference than the weights show, as the deposits are fluffy and occupy considerable space. As previously mentioned, the relative amounts can be judged closely by observation. The water treated with sodium bicarbonate is a more favorable water to use, as far as deposits on metal are concerned, but sufficient carbonic acid gas is not liberated to prevent deposition, even when so small a quantity of water as 50 gal. is used.

As sodium carbonate had proved inefficient in preventing deposition on metals, the well-known method of carbonating the filtered water was next tried. The apparatus set up for treating the water with carbonic acid gas was as follows: A hard glass tube, of 300 cu. cm. capacity, graduated in cubic centimeters, was fastened in an upright position. A two-holed rubber stopper was fitted to the lower end, one hole serving as the inlet for carbonic acid gas generated in a Kipp apparatus, the other attached by rubber tubing to a Mariotte bottle filled with water saturated with carbonic acid gas. The top of the tube was fitted with a one-holed stopper from which a bent glass tube led outward and down about 10 cm. To this arm a 10-cu. cm. pipette was connected by a short piece of rubber tubing. The pressure was controlled by the movable bottle, as in the case of an Orsat apparatus, and the flow of carbonic acid gas by pinch-cocks. A gallon bottle, filled with city water, was placed over the outflow, the pipette reaching to the bottom of the bottle. The top of the bottle was partly closed by close-fitting cardboard. The water was now carbonated very slowly, at the rate of about 10 bubbles per minute. When the desired amount of gas had passed into the water, the bottle of carbonated water was carefully removed, closed with a tight-fitting rubber stopper, and shaken for 5 min. At the end of that time it was transferred to a carboy and the proceeding was repeated. Two carboys, holding 25 gal., were filled for each experiment. Varying amounts of carbonic acid gas were passed into the water in the different experiments, the desire being to find the least amount of gas that would prevent deposition on metals. After the carboys were filled, the water was siphoned over plates of zinc and galvanized iron, as usual, at the rate of 1 gal. per hour for each kind of metal used. The results of the experiment are shown in Table 39.

It will be noticed from Table 39 that two figures may be chosen from the amount of carbonic acid gas to be passed into the water. Water carbonated at the rate of 20 cu. cm. of carbonic acid gas per liter will leave no deposit on metals; but the gas used in this quantity attacks the metals appreciably. Carbonic acid gas added at the rate of 13 cu. cm. per liter, on the other hand, leaves a very slight deposit, but the loss in weight of the metal is very much lower. Carbonic

Mr. Sole. acid gas at the rate of 20 cu. cm. per liter would be about 325 lb. per million gallons. Pressure and temperature corrections were not made, as these experiments are roughly quantitative only.

TABLE 39.—ACTION OF CARBONATED FILTERED WATER ON ZINC AND GALVANIZED IRON.

Liters of water treated.	CO_2 added per liter, in cubic centimeters.	Free CO_2 in treated water, in parts per million.	Loss in weight of zinc, in milli-grammes.	Loss in weight of galvanized iron, in milli-grammes.	Deposit on metals.	Deposit in bottles.
100	100	63	58	56	None.	None.
100	33	19	14	15	"	"
100	20	14	17	17	"	"
100	13	10	5.6	2.4	"	Slight.
100	8	2	0.0	3.4	Slight.	Large.

The results of this study may be summarized as follows:

First.—It is established that water softened by lime and soda and coagulated by alum or iron will appreciably attack zinc, black iron, and galvanized iron, and form heavy deposits.

Second.—In the case of zinc and galvanized iron, the deposits are similar in composition, and consist of about 90% of normal or basic carbonate of zinc.

Third.—Other salts present in the water in large quantities, such as carbonate of lime and magnesium, and sodium sulphate, are also present in the deposits to an appreciable extent, and are probably carried down by mechanical action.

Fourth.—Lead is practically unaffected, undergoing surface oxidation only, but receiving no deposit.

Fifth.—Black-iron pipe is heavily oxidized, copious deposits of iron oxide being formed and settling out to form a heavy sludge.

Sixth.—The dissolved oxygen in the water appears to have a corrosive action on the metals, which is aided by a carbonation, secured, first, either from the carbonic acid gas in the air, which is sufficient to form a normal or basic carbonate, but not sufficient to carry the deposit back into solution as bicarbonate; or, second, from the normal carbonates present in the filtered water, which are precipitated out as insoluble carbonate of zinc. No reduction in normal carbonates in the water that had passed over the metals could be detected, but so small a quantity as was taken for titration, namely, 100 cu. cm., would not bring out the difference.

Seventh.—A distilled water containing normal carbonate of lime forms deposits, indicating that this salt is a factor in the formation of deposits.

Eighth.—The same is true of carbonate of magnesium, to a less extent.

Ninth.—The presence of considerable amounts of sodium sulphate in the water does not appreciably affect the deposits. Mr. Sole.

Tenth.—Water containing considerable amounts of caustic favor the reduction of deposits.

Eleventh.—Sodium bicarbonate used as a chemical for the reduction of incrustants in water, that is, chlorides, sulphates, and nitrates of lime and magnesium, is no more nor less efficient than the normal carbonate of soda. Used as a chemical for the reduction of normal carbonates by the liberation of carbonic acid gas, it is efficient to the extent of about 20 parts per million. Used as a chemical for the prevention of deposits in pipes, it is unsatisfactory, reducing the deposits appreciably, but not eliminating them.

Twelfth.—Carbonation of the water is an efficient means of preventing the formation of deposits, but when used in sufficient amount the metals are attacked to an appreciable extent by the presence of free carbonic acid gas in the water.

C. P. Hoover, Esq.* (by letter).—In reference to Mr. Gregory's statement regarding the removal of bacteria, it might be of interest to state briefly some of the factors that influence bacterial removal at the Columbus Water Purification Works. Mr. C. P. Hoover.

Bacterial removal at these works was governed in 1909 by, (*a*) the amounts of calcium and magnesium salts precipitated from the water; (*b*) the amount of coagulant added to the water; (*c*) the addition of calcium hypochlorite; and (*d*) the method of operating the filters.

Removal of Bacteria by Water-Softening Precipitation.—When the river water is very hard high bacterial efficiency is obtained by adding very little, or no coagulant. The precipitate of magnesium hydrate is gelatinous, and shows about the same degree of efficiency for the removal of bacteria, as the hydrate precipitates of iron and alumina. The precipitated carbonates are pulverulent, and are not as effective in the removal of bacteria. During January and the first thirteen days of February, dependence was placed entirely on the water-softening precipitation for the removal of bacteria. The effectiveness of this treatment is shown by Table 40, which gives the average amounts of magnesium hydrate and calcium carbonate precipitated from the river water, and shows the average bacterial counts

TABLE 40.

Magnesium hydrate precipitated, in parts per million.	Calcium carbonate precipitated, in parts per million.	Bacteria per Cubic Centimeter.		
		River water.	Settled water.	Filtered water.
70	308	540	31	5

* Asst. Chemist, Columbus Water Purification Works.

Mr. C. P. Hoover. in the river, settled, and filtered water, expressed in numbers per cubic centimeter. The bacterial removal was 99 per cent.

Removal of Bacteria by Coagulation.—From the middle of February until the end of the year, either sulphate of iron or sulphate of alumina was added to the water. The quantities of coagulant added were proportioned by the amount and character of the turbidity, and varied from 0.3 to 8.3 grains per gallon. The average turbidity of the river water for the year has been 86 parts per million, and an average of 1.7 grains per gallon of coagulant has been added. Table 41 gives the average amounts of coagulant added to the river water.

TABLE 41.

Turbidity of river water between:	Coagulant added, in grains per gallon.	Turbidity of river water between:	Coagulant added, in grains per gallon.
10 and 25	1.1	150 and 200	4.4
25 " 50	1.2	200 " 300	4.2
50 " 75	1.9	300 " 500	5.2
75 " 100	2.2	500 " 1 000	4.7
100 " 150	2.8	1 000 " 1 500	6.4

The period of sedimentation was about 12 hours.

The number of bacteria in the river water during 1909 averaged 9 240 per cu. cm., in the settled water, 664, and in the filtered water, 120. These averages show that 92.8% of the total number of bacteria was removed in the settling basins, and that 5.9% more was taken out by filtering, making a total removal of 98.7 per cent.

TABLE 42.

Month, 1909.	Average Number of Bacteria per Cubic Centimeter, in:		
	River water.	Settled water.	Filtered water.
January	435	12	4
February	33 000	2 100	80
March	18 000	800	80
April	8 500	850*	250*
May	16 500	3 500*	700*
June	4 000	180*	120*
July	4 000	42	13
August	1 900	85	29
September	1 200	65	23
October	700	100	23
November	1 300	60	76
December	21 500	65	11

* The large numbers of bacteria found in the settled and filtered waters during April, May, and June belonged to a species which grew in the settling basins.

Table 42 shows the average of the daily counts, on the river, settled, and filtered water, for the year. The samples were plated in

duplicate on agar, having an acidity of 1%, and were incubated for 48 hours at 20° cent. Mr. C. P. Hoover.

Although the counts for the filtered water average 120 per cu. cm. for the year, the numbers were below 100 during 79% of the time; below 50 during 72% of the time; below 25 during 56% of the time; and below 10 during 39% of the time. On 20 days the plates were sterile.

The high numbers of bacteria, which appeared occasionally and hung on for two or three weeks at a time, were due, in almost all cases, to growths of a non-pathogenic bacterium, which develops in the lime sludge in the settling basins and conduits. The sludge contained about 5 000 000 or 6 000 000 bacteria per gramme, and every time this sludge was stirred up in the last chambers of the settling basins large numbers of bacteria were found in the settled and filtered water. The organism which caused the high counts will not grow at 37° cent. on any of the laboratory culture media, but develops on all media at 20° cent. Many times this organism caused the settling basin counts to be higher than the river water, and on a few occasions the filtered water counts have been higher than those of the raw river water for a similar reason.

The counts on gelatin and agar have checked very satisfactorily at all times on the river water, and also on the settled and filtered water, except during times when there was trouble with these growths; then the gelatin plates showed many times as many of these tiny white colonies as were developed on agar.

Disinfection with Calcium Hypochlorite.—The first experiments were made in the laboratory, at a time when trouble was caused by growths in the settling basin. Four samples of settled water (1 gal. each) were collected in sterile bottles; the hypochlorite was added, and the samples were shaken vigorously for 15 min., then gelatin plates were poured. These plates were incubated at 20° cent. for 48 hours. The results of the hypochlorite treatment are given in Table 43.

TABLE 43.

Sample No.	Available chlorine added, in parts per million.	Bacteria per cubic centimeter.
1	0.0	20 000
2	0.25	112
3	0.50	10
4	0.75	1

On December 15th the treatment of the entire supply with calcium hypochlorite was commenced. The river was in flood, and the turbidity and numbers of bacteria were very high. Table 44 shows the

Mr. C. P. Hoover. numbers of bacteria found in the river water, the settled water, before the application of the hypochlorite, the treated settled water, the filtered water, and also the presence or absence of *B. Coli* in 1-cu. cm. and 50-cu. cm. portions of the filtered water.

TABLE 44.—NUMBERS OF BACTERIA PER CUBIC CENTIMETER WHICH DEVELOPED ON AGAR PLATES, INCUBATED 48 HOURS AT 20° CENT.

1909, December.	River water.	Settled water before treatment.	Settled water, treated.	Filtered water.	Av. Cl., in parts per million.	*B. Coli* PRESENT: 1-cu. cm.	*B. Coli* PRESENT: 50-cu. cm.
16	86 000	1 750	350	24	....	+	+
17	61 000	.....	70	22	....	0	0
18	103 000	.....	20	10	....	+	+
19	77 000	3 600	255	28	....	0	+
20	41 000	1 650	43	21	0.78	0	+
21	53 000	6 200	68	1	1.00	0	0
22	80 000	1 400	52	40	0.42	+	+
23	20 000	1 000	46	7	0.27	0	0
24	21 000	80	27	80	0.55	0	+
25	18 000	80	32	2	0.10	0	0
26	13 000	118	6	1	0.16	0	0
27	2 500	12	15	0	0.40	0	+
28	6 000	350	11	1	0.17	0	0
29	9 000	52	19	9	0.25	0	+
30	4 500	106	21	4	0.27	0	0
31	8 400	228	10	6	0.28	0	+

There was considerable variation in the application of hypochlorite because of irregularity of pumping, and also on account of some mechanical difficulties with the dosing device.

Daily analyses were made for the determination of *B. Coli* in 1-cu. cm. portions of the river water and in 1-cu. cm. and 50-cu. cm. portions of the filtered water, according to the following procedure:

(*1*).—The filtered and river water samples, in 1-cu. cm. portions, were plated on lactose azolitmin Parietti agar, and after incubating 24 hours at 37° cent. four characteristic colonies, when present, were inoculated on agar slopes. From the slopes they were transferred into fermentation tubes of lactose bile (1% of lactose and ½% of peptone). If 25% of gas developed in the bile tube, then full determinative tests for *B. Coli* were made according to the procedure outlined in "Standard Methods of Water Analysis."

(*2*).—The samples, in 1-cu. cm. portions, were also inoculated into fermentation tubes of dextrose broth and lactose bile. The bile tubes were incubated 48 hours at 37° cent., and if any gas developed lactose azolitmin Parietti agar plates were poured. Whenever present, characteristic colonies were transferred to agar slopes and tested for *B. Coli*. The dextrose broth tubes were incubated at 37° cent. for 24 hours and plates were poured from tubes showing gas. If the tubes showed no gas but had turbidity then 1 cu. cm. of the broth was

Mr. C. P. Hoover.

TABLE 45.—NUMBER OF TIMES *B. Coli* WERE ISOLATED FROM 1-CU. CM. PORTIONS OF RIVER AND 1-CU. CM. AND 50-CU. CM. PORTIONS OF FILTERED WATER, FROM APRIL TO DECEMBER, 1909.

	APRIL.			MAY.			JUNE.			JULY.			AUGUST.			SEPTEMBER.			OCTOBER.			NOVEMBER.			DECEMBER.		
Date.	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F.	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F.	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F.	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F.	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F	1 cu. cm R.	1 cu. cm. F.	50 cu. cm. F.	1 cu. cm. R.	1 cu. cm F.	50 cu. cm. F.	1 cu. cm. R.	1 cu. cm. F.	50 cu. cm. F.
1..........	0	0	0	0	0	0	4	0	0	2	0	0	3	0	0	0	0	0	4	0	1	0	0	0	6	0	0
2..........	0	0	0	3	0	0	1	0	0	2	0	0	4	0	0	3	0	1	0	0	0	0	0	0	5	0	0
3..........	2	0	0	1	1	2	4	0	0	0	0	0	0	0	0	2	0	0	2	0	0	1	0	0	4	0	0
4..........	0	0	0	5	0	2	2	0	0	1	0	0	0	0	0	6	0	0	2	0	0	0	0	0	3	0	0
5..........	0	0	0	5	0	1	3	0	0	1	0	0	1	0	0	3	0	2	0	0	0	0	0	0	5	0	1
6..........	4	0	0	3	0	0	2	0	0	0	0	0	6	0	0	3	0	2	0	0	0	0	0	0	2	0	3
7..........	3	0	0	4	0	0	7	0	0	1	0	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0	0
8..........	0	0	0	4	0	0	4	0	0	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
9..........	1	0	0	0	0	0	3	0	0	4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10..........	1	1	0	4	0	0	3	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0
11..........	2	0	0	4	0	0	1	0	0	4	0	0	3	0	0	2	0	2	2	0	0	0	0	0	1	0	0
12..........	1	0	0	5	0	0	3	0	0	4	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
13..........	3	0	1	4	0	0	5	0	0	6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	0
14..........	2	0	0	4	0	0	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0
15..........	4	0	1	2	0	0	1	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	5	1	1
16..........	0	0	0	3	0	0	3	0	0	3	0	0	5	0	0	0	0	0	3	0	0	0	0	0	5	1	3
17..........	1	0	0	3	0	0	2	0	0	4	0	0	2	0	0	5	3	4	0	0	0	3	0	0	7	0	0
18..........	0	0	0	6	0	0	2	0	0	3	0	0	4	0	0	4	0	0	0	0	0	1	0	0	3	3	1
19..........	0	0	0	2	0	0	3	0	0	3	0	0	1	0	0	2	0	0	0	0	0	0	0	0	4	0	3
20..........	0	0	0	2	0	0	3	0	0	2	0	0	3	0	0	2	0	0	0	0	0	0	0	0	3	0	1
21..........	5	0	0	2	0	0	3	0	0	1	0	0	5	0	0	6	0	0	1	0	0	0	0	0	2	0	0
22..........	5	0	0	4	0	0	4	0	0	2	0	0	0	0	0	3	0	0	2	0	0	0	0	0	3	2	1
23..........	0	0	0	7	0	0	4	0	0	5	0	0	2	0	0	3	0	0	2	0	0	1	0	0	4	0	0
24..........	3	0	0	2	0	0	4	0	0	2	0	0	1	0	0	4	0	0	2	0	0	1	0	0	5	0	1
25..........	2	0	0	2	0	0	2	0	0	4	0	0	0	0	0	0	0	0	5	0	0	0	0	0	2	0	0
26..........	2	0	0	4	0	0	3	0	2	1	0	0	2	0	0	1	0	0	4	0	0	0	0	0	4	0	0
27..........	0	0	0	3	0	0	3	0	0	3	0	0	2	0	0	2	0	0	1	0	0	4	0	0	1	0	1
28..........	0	0	0	0	0	0	7	0	1	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	0	0
29..........	0	0	0	2	0	0	3	0	0	2	0	0	1	0	0	3	0	0	0	0	0	6	0	0	5	0	3
30..........	0	0	0	4	0	0	2	0	0	2	0	0	3	0	0	0	0	0	0	0	0	4	0	0	1	0	0
31..........	..	..	..	2	0	0	..	..	..	2	0	0	1	0	0	..	..	..	0	0	0	..	..	..	2	0	1
Totals...	41	1	2	96	1	5	95	0	3	74	0	0	55	0	0	59	3	12	38	0	1	23	0	0	101	7	20

Mr. C. P. Hoover. transferred into a lactose bile tube and incubated 48 hours, plates being made if the tubes developed gas. All plates were fished, and cultures were treated as in Procedure *1*.

(*3*).—Samples of the filtered water, in 50-cu. cm. portions, were mixed with 10 cu. cm. of enrichment medium (a solution of dextrose broth of five times normal strength). The mixture was incubated at 37° cent. for 24 hours, and then 1 cu. cm. of the solution was transferred into a lactose bile fermentation tube which was cared for in the same way as in Procedures *1* and *2*.

Table 45 shows the number of times that *B. Coli* were isolated from the river and filtered water from April 1st, 1909, to January 1st, 1910.

The filtered water, except on one or two occasions, has never given more than a bubble of gas in dextrose broth or in lactose bile, and no red colonies were ever found on lactose azolitmin Parietti agar. Dextrose broth tubes show some turbidity at times, and by transferring 1 cu. cm. of the broth into a lactose bile fermentation tube, there was sometimes obtained more than 25% of gas production; and on twelve occasions during the year it was possible to isolate *B. Coli* from 1-cu. cm. portions of the filtered water by the foregoing method. From 50-cu. cm. portions of the filtered water, *B. Coli* were isolated 43 times during the year, and on 26 different days. *B. Coli* were found to be present in 1-cu. cm. portions of the river water 71% of the time.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will be reproduced in the volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

HENRY FURLONG BALDWIN, M. Am. Soc. C. E.*

DIED JUNE 17TH, 1909.

Henry Furlong Baldwin died of apoplexy, at Seattle, Wash., on June 17th, 1909. By his death the Engineering Profession has sustained the loss of an eminent and forceful engineer, many members of this Profession, both young and old, have lost a strong and helpful friend, and the members of his family a dutiful brother, a kind and loving father, and an affectionate husband, for Mr. Baldwin was something more than a fine engineer, he was every inch a man.

He was born in 1862, the second of nine children, in Anne Arundel County, Maryland, of sturdy parents of Scotch-Irish and English descent. He was educated in the public schools, in the Anne Arundel Academy, and at the Massachusetts Institute of Technology, from which he was graduated in 1884, in the mechanical engineering course. He married Miss Pauline duPont, of Louisville, Ky., who, with three children, Paulina, Henry, and Meta, survives him.

After graduation, Mr. Baldwin chose to enter railroad work, and his first engagement was on the Cincinnati Division of the Louisville and Nashville Railroad until 1885. For a brief period afterward he was Rail Inspector at various steel mills. From 1885 to 1887, he was Supervisor of Track of the Knoxville Branch of the Louisville and Nashville Railroad, and for a short time in 1887 Roadmaster of the Pensacola and Atlantic Division of the Louisville and Nashville line. From 1887 to 1889, he was Roadmaster of the South and North Alabama Division of the Louisville and Nashville, at Birmingham.

From August, 1889, to March, 1890, Mr. Baldwin was Roadmaster on the Delaware Division of the New York, Lake Erie and Western Railway. From 1890 to 1894, he was Chief Engineer of the Chicago and Eastern Illinois Railroad. During this time a large portion of this road was rebuilt, involving a great deal of heavy work in the way of new masonry and bridge construction and reduction of grades, etc., also the construction of several new branch lines.

In May, 1894, Mr. Baldwin became Chief Engineer of the Chicago, Peoria and St. Louis Railway Company of Illinois, at Springfield, which position he held until he accepted that of Engineer of Maintenance of Way with the Erie Railroad, with office at Jersey City, N. J.

*Memoir prepared by W. D. Taylor, M. Am. Soc. C. E

He remained with the Erie until April, 1900, when he became Chief Engineer of the Chicago and Alton Railroad, with office at Chicago.

As Chief Engineer of the Chicago and Alton Railroad, Mr. Baldwin had charge of track maintenance, grade reduction, double-track construction, and the general rehabilitation of the property during the administration of S. M. Felton, M. Am. Soc. C. E. In 1904, he left the railway field and took a position as Vice-President of the duPont Powder Company, in charge of the Smokeless Powder Department, with office at Wilmington, Del. After three years of service with this company, he was appointed Chief Engineer of the Oregon and Washington Railroad, of the Harriman lines, with headquarters at Seattle, which position he held at the time of his death.

Mr. Baldwin was a man of forceful character and fine executive ability. He had a keen sense of humor, and frank, strong, manly qualities which easily won respect, confidence, and friendship. He loved to encourage and to show hospitality to the young men who worked for him. When his assistant engineers came in off the road to report to him, he would not permit them to go to hotels, but opened his home to them, and his delightful family made them welcome.

The writer was proud of the personal friendship of Mr. Baldwin. For the last four years, he has occupied the position on the Alton, which was held so long by Mr. Baldwin, and he has reason every day of his professional life to feel thankful for the character of the structures built and for the durable work done by this conscientious and thorough engineer.

Mr. Baldwin was a Member of the Western Society of Engineers, of the Chicago Club, of the Manhattan Club of New York City, and of the Rainier Club of Seattle, Wash.

Mr. Baldwin was elected an Associate Member of the American Society of Civil Engineers, on December 7th, 1892, and a Member, on February 6th, 1895.

CLIFFORD BUXTON, M. Am. Soc. C. E.*

Died January 12th, 1910.

Clifford Buxton was born on June 15th, 1844, in Warren, Me. He was the only son of Doctor Benjamin F. Buxton, who was prominent in the medical profession of his State, having gained renown, in Mexico and the South, fighting the dreaded disease, yellow fever.

Clifford Buxton was recognized as a bright boy, and early became interested in the study of mathematics. Through an error on the part of his father in purchasing for him a Smith's Trigonometry and Sur-

* Memoir prepared by R. P. Black, Assoc. M. Am. Soc. C. E.

veying, instead of an algebra, he became so interested that he took up surveying, thus beginning his professional career. At the age of fifteen, he and his chum, the late Frederic W. Vaughan, M. Am. Soc. C. E., who, in later years, became an eminent bridge engineer, succeeded in securing an old surveyor's compass and a four-rod chain with which they made surveys of every lot in their native village.

In 1861, Mr. Buxton was a Chainman on a survey of public lands in Northern Maine. In September, 1862, he entered Rensselaer Polytechnic Institute, from which he was graduated with high standing in July, 1865.

Shortly after his graduation Mr. Buxton entered the service of the Troy and Boston Railroad Company (now part of the Boston and Maine), first as a Leveler, and afterward as Draftsman. In the spring of 1866 he was engaged as Draftsman for the Pittsburg, Fort Wayne and Chicago Railway Company, and, being desirous of getting experience in construction, he accepted a position as Leveler for the Cleveland and Mahoning Railroad (now part of the Pennsylvania Lines), to work on a proposed extension of the line from Youngstown, Ohio, to Pittsburg, Pa. At this time, however, only the surveys were made. In July, 1866, he was appointed Assistant Engineer, under William H. Searles, M. Am. Soc. C. E., on the Allegheny Valley Railroad, then being extended to Franklin, Pa., which service terminated with the completion of the division under his charge.

In October, 1867, Mr. Buxton was engaged as Leveler on the preliminary surveys for the Knox and Licking Railroad (now a part of the Maine Central), after which he was appointed as Principal Assistant Engineer in charge of the location and construction of thirty miles of the same road; this was completed in 1871.

In July, 1871, he was appointed United States Assistant Engineer in charge of the surveys of Horse Shoe Shoals, Delaware River, under Lieutenant-Colonel J. D. Kurtz. He resigned this position to accept that of Principal Assistant Engineer of the Cleveland, Mount Vernon and Delaware Railroad (now part of the Pennsylvania Lines, West), where he remained until the completion of the railroad. In July, 1874, he was appointed Assistant Chief Engineer of the Scioto Valley Railroad (now part of the Norfolk and Western), then under construction, remaining until the completion of the road.

In May, 1879, Mr. Buxton became Assistant Chief Engineer of the Columbus and Sunday Creek Valley Railroad (now a part of the Toledo and Ohio Central Railway). On February 1st, 1881, he was elected Chief Engineer of the Toledo and Ohio Central Railway, which position he held until his death on January 12th, 1910. He also served as Chief Engineer of the allied railroads, the Kanawha and Michigan Railway, until July, 1909, and after July, 1909, of the Zanesville and Western Railway.

Mr. Buxton was married to Miss Lucinda M. Andrews, of Warren, Me., on December 9th, 1868. He was a Thirty-second Degree Mason and a member of the Order of the Mystic Shrine.

Mr. Buxton was one of the pioneer engineers of railroad building in the East and Middle West. Many a monument to his career, in the way of masonry bridges, yet remains on several of the trunk lines to bespeak his ability. He was an engineer of exactness, a man of few words, of strong character, and a personality which marked him as an individual. It is said of Mr. Buxton that he could impart more information in a few pencil notes than another man could in lengthy letters.

He is survived by his wife and daughter, his only child, Mrs. Hubert B. Turner, of Boston, Mass.

Mr. Buxton was elected a Member of the American Society of Civil Engineers on May 6th, 1885.

WILSON CROSBY, M. Am. Soc. C. E.*

Died December 18th, 1904.

Wilson Crosby, son of William Chase Crosby and Harriet Chase, was born in Atkinson, Me., on October 18th, 1834. He was the eldest son in the eighth generation from Simon Crosby who settled in Billerica, Mass., in 1635, having come to the United States from Lancashire, England. The family traces back to 1204.

Wilson Crosby received his education through the public schools. In 1851, he entered Rensselaer Polytechnic Institute, at Troy, N. Y., and was graduated from the four-year course in Civil Engineering, after three years' work, in 1854. He practiced his profession with the New York and New England Railroad Company, in Connecticut; with the Maine Central Railroad, and with the European and North American Railroad, in Maine; with the New York, Utica, and Ogdensburg Railroad; with the Racine and Mississippi Railroad; with the Canada, Michigan, and Chicago Railroad; with the Spring Hill and Parsborough Railroad; and also on the Poughkeepsie Bridge approaches. For many years he was associated with Mr. Luther H. Eaton, as "Eaton and Crosby," at Bangor, Me.

At the outbreak of the Civil War, Mr. Crosby was put in charge, for the Government, of some construction at Fort Knox, Maine. He soon, however, helped raise a company of infantry, and went into active service as Second Lieutenant, Company I, 14th Maine Volunteers. He served until mustered out on September 25th, 1865, when he resumed the practice of his profession in New York City and elsewhere. He was connected for a time with work on Central Park and

* Memoir prepared by W. W. Crosby, M. Am. Soc. C. E.

also on Riverside Drive. Later, as Division Engineer, he had charge of a part of the construction of Prospect Park, Brooklyn, including that porition known as "The Plaza."

In 1882-83, a company proposed to build an underground railroad and street under Broadway, in New York City, and Mr. Crosby was made Chief Engineer. Plans for "The Arcade" were prepared under his direction, but the capital not being forthcoming, the scheme was abandoned. In 1887, he was selected jointly by the New York and New England Railroad and the New York, New Haven and Hartford Railroad Companies to act as Chief Engineer for both companies in the abolishment of the grade crossings in Hartford, Conn., which he carried through to a successful conclusion. Such work was new then, and precedents for details were correspondingly scarce. The 80-ft. plate girders spanning Asylum Street were considered curiosities.

Mr. Crosby's father had died in 1880, and had left to his executorship several thousand acres of timber lands. About this time (1888), it became evident that he would have to devote practically his entire time to caring for this property, or the lands would have to be disposed of, probably at considerably less than their true value. The property was shared by his stepmother, his sister, and two brothers. With characteristic self-sacrifice, he thereupon made his decision, abandoned his beloved profession, in which he was just beginning to feel that he had won a substantial footing, and, in Bangor, Me., devoted his entire time to caring for the property which meant so much to others. With his usual thoroughness, he performed his new work and eventually made a success of it, though, for many years, the comparisons between his actual conditions and those which appeared to be promising in his profession at the time of his leaving it were sharp. Quietly and unobtrusively his deeds established for him such a record of uprightness, good judgment, honesty, and generosity, that many sought his help and advice in business affairs, and much property was entrusted to his guardianship. His business interests lay mostly in timber lands, and he early realized the dangers of forest destruction. The Maine Lumbermen and Land Owners Association he served faithfully, being one of its originators, and, for eight years, its Secretary and Treasurer. He was one of the first to demand the improved method of sawing rather than axing down trees. His plan met with much ridicule at first, but he clearly saw the advantages, patiently persisted, and finally had the satisfaction of seeing his ideas generally adopted.

For some time before his death, Mr. Crosby's health showed the strain he had undergone by his unselfish devotion to duty and unremitting attention to business affairs. His physicians advised him to take a complete rest, but his feeling of responsibility for the trust reposed in him by his father, and his belief that his utmost efforts were still necessary to fulfill that trust properly and to protect the

property from the ravages of those who sought to despoil it through technicalities, made him unwilling to consider himself. In October, 1904, he was finally persuaded by his family to remove to the residence of his son in Baltimore, Md., but his death from uræmia followed within two months.

As an Engineer, Mr. Crosby possessed attainments of an exceptionally high order, much higher than the opportunities afforded by his limited practice of his profession allowed him to demonstrate. His native modesty and diffidence, together with the interruption of his professional work referred to, prevented the proper exemplification of his abilities to the world at large, though they were well known to his intimates. He combined, in a superlative degree, knowledge, thoroughness, honesty, and energy. While his professional acquaintances and work will bear witness to these statements, probably his greatest contribution to the Profession and the common weal came from his kindly and improving influence on those fortunate enough to have been his subordinates or co-workers.

In November, 1871, Mr. Crosby married Miss Hannah Adelaide Seaver, daughter of William Whitney Seaver, of Brooklyn, N. Y. They had two children, Miss H. Gertrude Crosby and Walter Wilson Crosby, M. Am. Soc. C. E., who, with Mrs. Wilson Crosby, now live in Baltimore, Md.

Mr. Crosby was a Member of The Sons of the American Revolution, of the Loyal Legion, and a Past Commander of Hannibal Hamlin Post, G. A. R., of which he was one of the founders. Mr. Crosby was a man of unusually high character, and his qualities of heart and mind endeared him in the highest degree to those who were favored with his intimate acquaintance. For many years he was a leading spirit and substantial support of the Unitarian Church, of Bangor, Me.

His epitaph reads:

"An upright, honorable, unpretentious, Christian gentleman: he has left an inspiring example of usefulness, kindliness, and ability, and an unblemished record of modest and true worth."

Mr. Crosby was elected a Member of the American Society of Civil Engineers, on September 15th, 1869.

JOHN HALL EMIGH, M. Am. Soc. C. E.*

Died January 6th, 1910.

John Hall Emigh was born in Malta, Saratoga County, New York, on November 19th, 1850. He was the son of William W. and Eliza (Hall) Emigh.

* Memoir prepared by E. R. Cary, M. Am. Soc. C. E.

After finishing his elementary education, he attended the State Normal School at Albany, N. Y., from which he was graduated in 1871. From 1871 to 1876 he taught in district schools. In April, 1876, he became a student at the Rensselaer Polytechnic Institute, from which he was graduated in June, 1879, with the degree of C. E.

The record of Mr. Emigh's professional engagements is as follows:

1879—Rodman on the Chicago and Alton Railroad in Illinois.

1880-81—Engineer and Draftsman for the Saratoga Victory Manufacturing Company, Victory Mills, N. Y.

1882-83—Transitman and Draftsman on the survey of the Boston, Hoosac Tunnel and Western Railroad, Western Division.

1883-96—Instructor in the Departments of Mathematics and Surveying at the Rensselaer Polytechnic Institute.

1896-1903—City Engineer of North Adams, Mass.

1903-10—Engaged in private practice in hydraulic and municipal work in the vicinity of North Adams, Mass.

Mr. Emigh was actively engaged in his professional work to within twenty-four hours of his death. Always having had good health, he had great capacity for work, and thoroughly enjoyed the active life which he led.

Taking up the municipal work of North Adams, Mass., when it became a city, he solved with care and skill the many troublesome problems which arose.

Mr. Emigh's friends will always remember him as a Christian man, ever ready to help by words and deeds every good cause in civic. charitable, church, or social work. In his private life, as in his professional work, he was reliable, clean, and straightforward. Kindliness, loyalty, and faithfulness in the performance of every duty, characterized his teaching and his professional work.

The esteem felt for him by those who were associated with him is well expressed by one of the Commissioners of the Greylock Reservation, the engineering work of which was under Mr. Emigh's charge, as follows:

"To those who know Mr. Emigh the news of his death came like a bolt from a clear sky. His was a most attractive personality. Thoughtful, conservative, of the best training, kindly in manner, he impressed all with whom he came in contact with his rugged honesty. In his chosen profession he was diligent, skillful, and his opinions were weighted with care and carefully stated. It was a pleasure to be associated with him in any undertaking. He had that broad common sense that could grapple with any problem presented. * * * He was the type of man that every community needs. Above all he was a Christian gentleman. We shall miss Mr. Emigh."

On March 3d, 1880, Mr. Emigh married Emma F. Allen, daughter of David Allen, of Malta, N. Y. His wife and one son, William C.

Emigh, a graduate of the Rensselaer Polytechnic Institute of the class of 1909, survive him.

Mr. Emigh was elected a Member of the American Society of Civil Engineers, on April 3d, 1901.

HENRY CYPRIAN HUMPHREY, M. Am. Soc. C. E.*

Died December 7th, 1909.

Henry Cyprian Humphrey, son of Cyprian Nicholas and Louise Davies Humphrey, was born in Ogdensburg, N. Y., on November 14th, 1859. After his father's death, in 1860, the family moved to Hartford, Conn., to the home of his grandfather, Lemuel Humphrey, who was one of the oldest settlers and most influential citizens of that city.

After going through the public schools of Hartford, Mr. Humphrey entered the Rensselaer Polytechnic Institute, from which he was graduated, in 1887, with the degree of C. E. After receiving his degree, he was appointed Assistant Engineer on the Rome, Watertown, and Ogdensburg Railroad, and remained with that road until it was merged with the New York Central and Hudson River Railroad.

He was then made Assistant Engineer of the Department of Public Works of the State of New York, which position he held until overwork obliged him to take a vacation. This vacation was spent in traveling through the Northwest, Alaska, Arizona, Cuba, Mexico, and South America, where he made extensive collections of minerals and flora. The excavations made by him in the country of the Cliff Dwellers made his collection rank among the most complete amateur collections extant.

In 1903, Mr. Humphrey was appointed District Engineer of the Philippine Islands, Lucena, Tayabas Province, Tayabas, etc. He remained in the Islands in this capacity, taking no vacation, until the winter of 1908, when his failing health rendered a rest and change of climate necessary.

Returning to the United States, Mr. Humphrey spent a quiet year with relatives in Odessa, N. Y., endeavoring to recuperate so as to return to the position in the Philippines which was held open for him. He suddenly became much worse, however, and passed away on December 7th, 1909.

Mr. Humphrey was a Member of the Delta Phi Club of New York City, the South American Exploration Company, and was a Free Mason.

In his work in his chosen profession, Mr. Humphrey was second to none, holding the respect of all who knew him in a business

* Memoir prepared by Miss Harriet Fairchild Blodgett.

capacity, and the love, admiration, and loyalty of all whom he honored with his friendship, for

"His was the most tender, true, and noble soul
That ever trod this world of ours as man."

Mr. Humphrey was elected an Associate Member of the American Society of Civil Engineers on September 4th, 1901, and a Member on October 3d, 1905.

HENRY MAYNADIER STEELE, M. Am. Soc. C. E.*

Died July 5th, 1909.

Henry Maynadier Steele was born in Baltimore, Md., on September 26th, 1865, and died in Asheville, N. C., on July 5th, 1909. He was a son of Isaac Nevett and Rosa (Nelson) Steele, of Baltimore. In 1882, he was graduated from the Shenandoah Valley Academy, at Winchester, Va., as valedictorian of his class. Then for two years he attended the Massachusetts Institute of Technology as a special student.

Mr. Steele began his active business career in 1885, with the Baltimore and Ohio Railroad, with which company he occupied various minor positions in the Engineering and Maintenance of Way Departments, until 1887, when he entered the service of the New York, Lake Erie and Western Railroad Company (now the Erie Railroad Company) as Assistant Engineer on the work of double-tracking the Northern Railroad of New Jersey from Bergen Junction to Cresskill.

From 1887 to 1890, he was in charge of the following work on the New York, Lake Erie and Western Railroad: The reconstruction of the Hackensack River draw-bridge on the main line; the construction of the East Buffalo coal storage plant; the double-tracking of the Jefferson Branch of the Erie Railroad; the reconstruction of the Delaware River crossing at Hancock; the construction of second-track on the Northern Railroad of New Jersey, from Cresskill to Sparkill; preliminary and location surveys and estimates for a proposed railroad from Buffalo to Tonawanda, N. Y.; and surveys and estimates for a proposed railroad from Carbondale to Honesdale, Pa. For a portion of this time, he was also detailed as Roadmaster on the Delaware Division.

In December, 1890, Mr. Steele was advanced to the position of Principal Assistant Engineer of the same road, in which capacity he had charge of all detail work in the Chief Engineer's Department. During this time he also had charge of the reconstruction of the Chambers Street and Pavonia Avenue ferry racks, North River; and

* Memoir prepared by Francis Lee Stuart, M. Am. Soc. C. E.

Pier No. 2, Shed No. 1, and a crib bulkhead and box sewer at Jersey City. The design and installation of interlocking and block signaling plants were also included in his general work; and, in August, 1891, he made a detailed inspection and report of all plants on the New York, Pennsylvania and Ohio Railroad and the Chicago and Erie Railroad, now parts of the Erie Railroad system. For some months, in the latter part of 1892, he was in charge of the Engineering Department of the New York, Lake Erie and Western Railroad, during the absence of the Chief Engineer.

Mr. Steele resigned in January, 1893, to establish the Southern Agency of the Hall Signal Company, with headquarters at Baltimore, Md., which position he held until April, 1894, when ill-health necessitated the stoppage of all active work for some time.

In the spring of 1894, he moved to Asheville, N. C., where for three years he was in consulting engineering practice. It was during this period that he was invited by the Society to prepare a paper, to be read at the Twenty-sixth Annual Convention at Niagara Falls, N. Y., on the subject of block signaling, but sickness prevented its final completion.

His health improving, in October, 1897, Mr. Steele was appointed Civil Engineer of the Central of Georgia Railway Company, reporting to the Vice-President. In this capacity he directed surveys and record maps of all terminals on that road, as well as the construction of the Andalusia extension of the Mobile and Girard Railroad. He designed the plant of the Atlantic Compress Company at Dotham, Ala.; constructed the Porterdale and Milledgeville Asylum spurs; and made a report on and an appraisal of the Kansas City Southern Railway and the Hawkinsville and Florida Southern Railway. In addition to his other duties at this time, he directed, as Chief Engineer, preliminary and location surveys, estimates, etc., of the Atlanta Belt Line.

In November, 1900, Mr. Steele was appointed Chief Engineer of the Central of Georgia Railway; and under his charge considerable work on the revision of grades and alignment was executed; many bridges were replaced with heavier structures; depots and warehouses, including the freight warehouse at Atlanta, Ga., and the passenger depot at Columbus, Ga., were rebuilt; the Henry Ellen Branch was extended into the Cahaba coal fields in Alabama; the Fort Oglethorpe and Army spur was built; and the Greenville and Newman Railway was partially completed. During this time he was also frequently called on as consulting engineer in connection with the design and valuation of cotton compress plants in Alabama and Mississippi.

In July, 1906, he was appointed Chief Civil Engineer of J. G. White and Company, Incorporated, of New York City, in charge of all civil engineering matters, with headquarters at New York City, which position he held at the time of his death. His duties during this

period were of a general nature, involving consultations covering a wide field of engineering; investigations of various projects, etc.; and also, in an administrative capacity, the carrying out of the construction work of the Norfolk and Southern Railway, in North Carolina, comprising 90 miles of railroad, as well as 40 miles of the Virginian Railway lines in Virginia.

In the spring of 1908, just after recovering from an attack of typhoid fever, Mr. Steele conducted, unassisted by Counsel, a very arduous arbitration proceeding in the case of J. G. White and Company, Incorporated, *vs.* the Norfolk and Southern Railway Company.

In February, 1894, he married Miss Margaret Hollins McKim, of Baltimore, who, with three children, survives him.

Mr. Steele was an able, energetic, and efficient engineer; a man of sterling character; with the highest ideals of courtesy, honor, and integrity. He had the confidence and esteem of all who came in contact with him. With the exception of a few years of illness, his entire life was devoted to his profession, and his untimely death cut short a career that gave promise of still further honor and success.

Mr. Steele was a Member of the American Railway Engineering and Maintenance of Way Association; the Forestry Association; the National Geographic Society; and of the Engineers', New York Athletic, and Rockaway Hunting Clubs.

He was elected an Associate Member of the American Society of Civil Engineers on April 5th, 1893, and a Member on December 6th, 1899.

JOHN JOSEPH HORAN, Assoc. M. Am. Soc. C. E.*

Died November 9th, 1909.

John Joseph Horan was born in New York City, in 1866. His father, John Horan, was a resident of Long Island City, where, for a number of terms, he held the office of City Treasurer, and where, for many years, his family was active in social and business life.

Mr. Horan was an only son, and received his education in the schools of New York City and in Cooper Union. In 1887 he became Superintendent of the Chemical Fertilizer Company, of Brooklyn, N. Y., and continued in this position until 1890, when he became Engineer in Charge of Construction of the works of the Clinton Metallic Paint Company, of Clinton, N. Y. He afterward became Superintendent in Charge of the operation of these works.

In 1896 he took charge of the construction of the petroleum refining plant of the Empreza Industrial de Patrolio, of Rio de Janeiro, Brazil.

* Memoir prepared by E. J. Fort, M. Am. Soc. C. E.

From 1898 to 1905, he was Superintendent of the extensive plants of Wilson Sons and Company, Limited, of London, England, at Rio de Janeiro and Bahia, Brazil, involving the operation of stone quarries, coaling stations, repairs to ships, tugs, and lighters, building of sea walls, maintenance of docks, wharves, etc.

In 1905, Mr. Horan returned to New York City, and after spending a few months as an Inspector in connection with the construction of the Pennsylvania Railroad tunnels under the North River, he obtained a position with the Board of Water Supply, on the construction force for the new Catskill Aqueduct. At the time of his death he was in charge of the borings for the proposed water distribution tunnel under New York City.

Mr. Horan's death occurred on November 9th, 1909, while he was on a short vacation to the Maine woods. While talking to friends at the door of the camp where he was staying, heart failure overtook him, and death came instantly. Apparently, he had been in the best of health and was in the prime of life.

Mr. Horan had that habit of mind which is characteristic of the successful engineer: painstaking attention to details, a love of mechanics, and a fair share of inventive genius. He had invented a number of mechanical contrivances which proved of value in the operation of paint and cement mills. He had perfected a rotary steam engine which operated with high efficiency. He was also responsible for the apparatus used by the Board of Water Supply to determine the condition of rock strata as to soundness in deep-rock borings along the line of the Catskill Aqueduct. He was thoroughly absorbed in his work, and, had not death so suddenly cut short his career, his continued success and an honored position in his profession were assured.

Mr. Horan was unmarried, and, with the exception of one sister, left no immediate family. He was of a disposition which made friends wherever he went, and those who knew him are unanimous in their testimony to his high character as a gentleman, his scrupulous integrity in all his transactions, and his faithfulness and generosity as a friend.

Mr. Horan was elected an Associate Member of the American Society of Civil Engineers on October 7th, 1908.

William B. Reed, and Alfred Noble, and the following resolution was adopted:

"*Resolved,* That the President be authorized to appoint a committee of five, of which he shall be Chairman, to consider the whole matter of licensing civil engineers in conformity with the recommendation of the Board of Direction, and to report at the next Annual Convention."

A paper by B. F. Cresson, Jr., M. Am. Soc. C. E., entitled "The New York Extension of the Pennsylvania Railroad: the Terminal Station-West," was presented by the author and illustrated with lantern slides.

F. Lavis, M. Am. Soc. C. E., presented his paper entitled "The New York Extension of the Pennsylvania Railroad: the Bergen Hill Tunnels," illustrating it with lantern slides.

The Secretary announced that the Forty-second Annual Convention of the Society will be held at Chicago, Ill., June 21st to 24th, inclusive, 1910.

The Secretary announced the election of the following candidates by the Board of Direction on April 5th, 1910:

As Members.

George Sydney Binckley, Vancouver, B. C., Canada.
Otto William Degen, Alameda Cal.
Oliver Dwight Filley, Manila, Philippine Islands.
Gustav Willy Gehler, Dresden, Germany.
Thomas Triplett Hunter Harwood, Boston, Mass.
George Jackson Henry, Jr., San Francisco, Cal.
Arthur Grant Holt, St. Maries, Idaho.
William Willett Lewis, Hyde Park, Mass.
Victor Henry Poss, San Francisco, Cal.
Charles Word Rollins, China, Tex.
James Stephenson, Jr., Boise, Idaho.
Morris Kinnard Trumbull, Chicago, Ill.
Kirby Calhoun Weedin, Morrison, Ill.
John Norman Spencer Williams, Kahului, Maui, Hawaii.

As Associate Members.

Akira Awoyama, Gatun, Canal Zone, Panama.
Webster Lance Benham, Oklahoma City, Okla.
Arthur Clarence Douglas Blanchard, Toronto, Ont., Canada.
Harry William Brown, Logansport, Ind.
Franz August Busse, Louisville, Ky.
Harold Dearborn Comstock, Pathfinder, Wyo.
John Thomas Dickerson, Chicago, Ill.
Richard Fahnestock Ensey, Palatka, Fla.
Otto Frederick Harting, St. Louis, Mo.
John J. Hill, Brewerton, N. Y.

James Henry Hood, Hauserlake, Mont.
Darwin Shaw Hudson, Astoria, N. Y.
Alfred Leon Jacobson, Paris, France.
Ferrand Seymour Merrill, Toledo, Ohio.
Simon Frank Nolan, Providence, R. I.
Ermon Miland Peck, Hartford, Conn.
John Herman Quimby, New York City.
Herbert Timothy Rights, Lansdowne, Pa.
James Howard Roach, Cleveland, Ohio.
Walton Harvey Sears, Boston, Mass.
George Herbert Shaw, Brooklyn, N. Y.
Edward Newton Sheffield, Gaylordsville, Conn.
Chester Alexander Smith, Kansas City, Mo.
Joseph Emmett Snell, Newark, N. J.
Ralph Wallace Whitaker, Vera Cruz, Mexico.

As Associate.

Bernard Rowntree, New York City.

As Juniors.

William Joshua Barney, New York City.
Vivian Dangerfield Beard, Ames, Iowa.
Charles Dow Calkins, Troy, N. Y.
Frank Dominic Cefalu, Burrwood, La.
Leon George Cutler, New York City.
Frederick William Doolittle, Boulder, Colo.
Herbert Cram Ellis, Detroit, Mich.
Harold Phillips Farrington, New York City.
William Frederick Fox, Long Island City, N. Y.
Homer More Hadley, Cordova, Alaska.
William Mahone, Jr., New Bern, N. C.
Donald Hebard Maxwell, Chicago, Ill.
Frederick Hermann Munkelt, Elmira, N. Y.
Charles Jerome O'Donnell, Walden, N. Y.
William Edmund Price, Oklahoma City, Okla.
Benjamin Strain, Maybrook, N. Y.
Nathaniel Augustine Thayer, New York City.
George Noble Toops, Pocatello, Idaho.
David Leroy Yarnell, Washington, D. C.

The Secretary announced the transfer of the following candidates by the Board of Direction on April 5th, 1910:

From Associate Member to Member.

Robert Farnham, Jr., Washington, D. C.
Eugene Grove Haines, Richmond Hill, N. Y.

CLIFTON STEWART HUMPHREYS, Madison Me.
MILO STUART MACDIARMID, Detroit, Mich.
JAMES WILLIAM MARTIN, Los Angeles, Cal.
HARRADON STERLING SMITH, Wilkes-Barre, Pa.
LAYTON FONTAINE SMITH, Baltimore, Md.
ARTHUR WEBSTER THOMPSON, Baltimore, Md.
THOMAS BRYAN WHITNEY, JR., New York City.

FROM ASSOCIATE TO ASSOCIATE MEMBER.

LEWIS EUGENE MOORE, Newtonville, Mass.

FROM JUNIOR TO ASSOCIATE MEMBER.

WILLIAM FLINT BIXBY, Los Angeles, Cal.
ROBERT HUSE BROWN, New York City.
HENRY SYDNEY HANCOCK, JR., Fort William, Ont., Canada.
CHARLES RAY HAWLEY, Harrisonburg, La.
HARRY NORTHROP HOWE, Memphis, Tenn.
HOWARD CHAPIN IVES, Worcester, Mass.
MILAN NIKOLITCH, San Francisco, Cal.
EDWARD PENDLEBURY, Arlington, N. J.
DONALD CRAMER WAITE, New York City.
CARL ROBERT WEIDNER, Madison, Wis.
HENRY CHRISTOPHER WESTOVER, Kansas City, Mo.
HAROLD S. WILLIAMS, Caldwell, Idaho.

The Secretary announced the following deaths:

LINUS WEED BROWN, elected Member June 7th, 1899; died March 7th, 1910.

CHARLES ALFRED HASBROUCK, elected Associate Member February 3d, 1892; Member, December 5th, 1894; date of death unknown.

JULIUS I. LIVINGSTON, elected Associate July 3d, 1889; died March 1st, 1910.

FRANK WALLACE WEBSTER, elected Associate Member May 6th, 1908; died February 15th, 1910.

Adjourned.

OF THE BOARD OF DIRECTION

(Abstract)

April 5th, 1910.—President Bensel in the chair; Chas. Warren Hunt, Secretary; and present, also, Messrs. Andrews, Belknap, Brackett, Churchill, Kimball, Knap, Loomis, Macdonald, Pegram, Schneider, Swensson, Talbot, and Thompson.

Chicago, Ill., was decided upon as the place, and June 21st-24th, inclusive, as the time, for holding the Forty-second Annual Convention of the Society.

The proposed legislation in the matter of licensing Civil Engineers was considered, and a Resolution adopted for presentation to the next meeting of the Society.*

The Secretary was instructed to present a formal request to the proper authorities in Mexico that the certificate of Corporate Membership of the Society when presented by members desiring to practice in Mexico be recognized.

Ballots for membership were canvassed, resulting in the election of 14 Members, 25 Associate Members, 1 Associate, and 19 Juniors, and the transfer of 9 Associate Members to the grade of Member, 1 Associate to the grade of Associate Member, and 12 Juniors to the grade of Associate Member.

The resignations of two Members and two Juniors were accepted.

Applications were considered and other routine business transacted.

Adjourned.

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* See page 160.

ANNOUNCEMENTS

The House of the Society is open from 9 A. M. to 10 P. M., every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

FUTURE MEETINGS

May 4th, 1910.—8.30 P. M.—Two papers will be presented at this meeting, as follows: "The Water Supply of the El Paso and Southwestern Railway, from Carrizozo to Santa Rosa, N. Mex.," by J. L. Campbell, M. Am. Soc. C. E.; and "The New York Tunnel Extension of the Pennsylvania Railroad: The Site of the Terminal Station," by George C. Clarke, M. Am. Soc. C. E.

These papers were printed in *Proceedings* for March, 1910.

May 18th, 1910.—8.30 P. M.—At this meeting, a paper by J. C. Meem, M. Am. Soc. C. E., entitled "Pressure Resistance and Stability of Earth," will be presented for discussion.

This paper is printed in this number of *Proceedings*.

June 1st, 1910.—8.30 P. M.—Two papers will be presented for discussion at this meeting, as follows: "The New York Tunnel Extension of the Pennsylvania Railroad: Meadows Division and Harrison Transfer Yard," by E. B. Temple, M. Am. Soc. C. E.; and "The New York Tunnel Extension of the Pennsylvania Railroad: The North River Tunnels," by B. H. M. Hewett and W. L. Brown, Members, Am. Soc. C. E.

These papers are printed in this number of *Proceedings*.

ANNUAL CONVENTION

The Forty-second Annual Convention of the Society will be held at Chicago, Ill., from June 21st to June 24th, 1910, inclusive.

The following committees to take charge of arrangements have been appointed:

Committee of the Board of Direction:

FRANCIS LEE STUART, W. L. GARDNER.
CHAS. WARREN HUNT.

Local Committee:

CHARLES F. LOWETH,
W. E. ANGIER, E. M. LAYFIELD,
C. H. CARTLIDGE, O. J. WEST.

As soon as possible, information will be furnished Members by circular, concerning transportation, hotel rates, etc.

PROPOSED LEGISLATION OF INTEREST TO ENGINEERS

BILL INTRODUCED IN HOUSE OF REPRESENTATIVES "TO INCREASE THE EFFICIENCY OF THE ENGINEER CORPS OF THE UNITED STATES ARMY."

At an informal meeting of Civil Engineers (not a meeting of the Society), at the Society House on January 25th, 1910, called "for the purpose of considering the relation of the Civil Engineer to the Public Works of the Country, and with particular reference to a bill now before Congress fixing the status of the Engineering Corps of the United States Army," a committee consisting of Charles Macdonald, Alfred Noble, William H. Burr, F. P. Stearns, and Samuel Whinery, was appointed to appear before the House Committee on Military Affairs, to which the above bill had been referred.

At a meeting of the Board of Direction of the American Society of Civil Engineers, on March 1st, 1910, the following resolution was unanimously adopted:

"*Resolved* that the Board of Direction heartily approves and endorses the action taken at a recent meeting of members of the Society in appointing a committee consisting of Charles Macdonald, Alfred Noble, William H. Burr, F. P. Stearns, and Samuel Whinery, with the object of urging suitable recognition of Civilian Engineers employed on River and Harbor Works, in the proposed legislation providing for an increase of the Engineer Corps of the Army."

On March 9th, 1910, this Committee had a hearing before the Committee on Military Affairs.

Mr. Macdonald, on April 5th, 1910, presented to the Board of Direction a copy of the following letter subsequently addressed to that Committee, which is a brief of the conclusions and suggestions of the representatives of the Civil Engineers' meeting first above referred to:

"Mr. J. A. T. Hull, Chairman,
"Committee on Military Affairs,
"House of Representatives,
"Washington, D. C.

"Dear Sir:

"On Wednesday, March 9th, the Committee on Military Affairs of the House of Representatives gave a hearing to a Committee of members of the American Society of Civil Engineers on matters relating to the *Bill H. R. 7 117,* entitled, A Bill to Increase the Efficiency of the Engineer Corps of the United States Army, at which Charles Macdonald and William H. Burr, members of the Committee of Civil Engineers, communicated certain statements to your Committee and

gave such evidence as was required by yourself and other members of your Committee. In order to lay before the Committee on Military Affairs, of which you are the Chairman, a somewhat more complete and concise statement of the arguments which we desire to make in favor of the proposed amendment to the *Bill H. R. 7 117* we desire to submit to you the following statement or brief, not as displacing in any particular whatever the communications and evidence made before your Committee on March 9th, but rather to complete and give greater force and effect if possible to what was said by this Committee before your honorable body on that date.

"We recommended that *Section 4 of H. R. 7 117,* A Bill to Increase the Efficiency of the Engineer Corps of the United States Army, be amended so as to read as follows:

" 'Sec. 4. That whenever it shall be necessary or advisable, in order to properly prosecute works of river and harbor improvement, the Chief of Engineers is authorized to appoint or detail for duty in charge of river and harbor districts, or as members of boards of engineers, any assistant engineers in the employ of the Engineer Bureau of the War Department. *Provided:* That assistant engineers so appointed or detailed shall, while so engaged, have the relative grade of Captain or Major in the Corps of Engineers, to be determined by the Chief of Engineers, and provided, further, that neither assistant engineers nor officers of the Corps of Engineers shall be detailed in charge of river and harbor districts or divisions until they have had at least five years' experience on river and harbor work.'

"The general purpose of this amendment is to increase the efficiency of the services both of the corps of engineers as a whole and of the civil engineers employed in that corps, by giving the civil engineers such recognition of rank or grade as the actual service performed by them justifies, all 'to be determined by the Chief of Engineers.' In making this recommendation we wish to be distinctly understood as making no statement or argument prejudicially affecting the proposed increase of the Engineer Corps of the Army contemplated in the Bill. It is our conviction that the desired recognition of the civil engineers in the service of the Engineer Corps of the Army should be made in the manner set forth in the proposed amendment to *Section 4,* irrespective of any other provision of the Bill. In other words, the proposed amendment is not intended to affect in any manner whatever other provisions of the Bill.

"As you are aware, many civil engineers are employed on works of river and harbor improvement under the general supervision of the engineer officers of the Army. In most cases the immediate execution of these works is placed in the hands of the civil engineers thus employed by the officers of the Corps of Engineers. On this sound basis of engineering experience many of them have become eminent in their professional attainments and have rendered service in positions of great actual responsibility in the design and construction of all parts of river and harbor works. They not only acquire great technical skill but are frequently called upon to organize forces for the economical and effective prosecution of works of great difficulty and importance. Such capacity receives substantial recognition in civil life, but on work

under the supervision of the Engineer Corps of the Army the civilian can never rise above the grade of Assistant Engineer, one of the lower grades in the civil engineering profession, a grade which in the service of the Government commands only relatively low pay and usually receives little credit for work done.

"The work of the civil engineer is rapidly becoming specialized, and the civil engineers employed on river and harbor works form a special class. Although by years of experience they become highly proficient in this specialty, as time passes, they take up other branches of professional work with increasing difficulty; yet a large number of civil engineers are withdrawing from this field and obtaining more remunerative work elsewhere. We believe that the civil engineers on the river and harbor works have had no small part in the efficient conduct of these works for which the Engineer Corps of the Army justly receives great credit. This credit belongs to the entire organization engaged upon these works—army and civil engineers together—and the efficiency of the service would be promoted by using to the full limit the capacity of all its parts.

"It may be confidently stated that even the most conscientious and able professional men cannot be expected to accomplish the most effective results for the Government under the circumstances. The great works throughout the country of private and public corporations, including municipal and state governments, exceeding in value many times that of the public works of all classes constructed by the federal government, are originated by civil engineers in nearly all cases. They are designed and constructed from their initial conception to their completion, and are subsequently maintained and operated by civil engineers. All the great organizations of office and field forces required in such works are, as a whole, created by civil engineers with an effectiveness and economy certainly not excelled in the execution of the works of the federal government.

"Many examples of effective organizations created by civil engineers might be cited, but we will mention only two, both of the highest importance:

"The first of these is the construction now in progress for the additional water supply of the City of New York. The estimated cost of the completed work is $160 000 000. The engineering force numbers about 500. In respect of ability, integrity and devotion to duty this organization is not excelled by any other within our knowledge, military or civil.

"The second example is the Panama Canal, which we think will be conceded to be the greatest engineering work ever yet undertaken. The entire organization of that great work was created and its successful operation for about two and a half years was conducted by civil engineers, so far as that organization affected the engineering work of the project. The Department of Engineering and Construction, the Department of Materials and Supplies, the general plan and layout of handling both dry and wet excavation throughout the entire extent of the work, the general features of its excavation, the character of appliances which have since been so effective in the phenomenal progress of the work as a whole, the general scheme of office and field organiza-

tion, as well as the hospital organization, the quarantine organization at both Colon and Panama and the sanitary work in all its branches throughout the whole extent of the canal; in fact, all the main features of the work were completely organized, put in effective working condition and accomplished results of magnitude within the first year of the life of the Isthmian Canal Commission, and it was so continued for the first two and a half years of the existence of that Commission, under a civil engineer as Chief Engineer, with an engineering organization created, maintained, and effectively managed by him; all of which can be verified by reference to the early annual reports and other official documents of the Isthmian Canal Commission. Undoubtedly there have been many subsequent developments in the progress of this great work under the admirably effective management of the Engineer Officers of the Army since they took charge of it. We have only expressions of praise for what they have done with such energy and efficiency, but it is a simple statement of fact that the original organization in all its parts which has since been found so well adapted to the accomplishment of its purpose was created in all its main features and set in efficient operation by civil engineers.

"The injustice to civil engineers employed on river and harbor works inherent in the present system has long been recognized by many fair-minded officers of the Corps of Engineers, but they have been powerless, under the existing laws, to remedy it. The amendment proposed to *Section 4* of the pending Bill, if enacted, will give full power to the Chief of the Corps of Engineers to remedy the injustice, with, we believe, great increase in efficiency of the organization as a whole and benefit to the public which it serves.

"The changes proposed to be introduced into *Section 4* by the draught submitted to you by our committee at the hearing on the 9th inst. are three: 1st—In the first line the words 'or advisable' are inserted after the word 'necessary,' so that the Chief of Engineers may not be constrained to follow a narrow interpretation of the term 'necessary;' the words inserted would increase his authority and give him the unquestionable right to assign his civil engineers to positions of greater responsibility when, in his opinion, the public interests would be served by such assignment; 2nd—By the provision of relative rank a standing would be given to civil engineers serving in such responsible capacity commensurate with the experience of the engineer and the importance of the duties performed; this would be particularly desirable while such engineers are acting as members of Boards of Engineers organized within the Corps. It would be a matter of simple justice, as well as good business administration of government affairs, to establish this relative equality of rank among engineers employed on like duties with like responsibilities; 3rd—Experience in engineering work is required by both civil and military employes of the Government before highly responsible duties can be assigned them. Instances have occurred where river and harbor districts have been placed under the charge of recent graduates from West Point, whose technical training and engineering experience would not have carried them, in civil life, beyond the grade of instrumentman. It is respectfully submitted that the public interests must be harmed by such

assignments, and that the duty would be better performed by an experienced assistant engineer.

"In the hearing before the Committee on Military Affairs questions were asked regarding the effect or advisability of the last provision of the proposed amendment, *i. e.*, 'that neither assistant engineers nor officers of the Corps of Engineers shall be detailed in charge of river and harbor districts or divisions until they have had at least five years' experience on river and harbor work.' It is believed by this committee that only engineers of skill and experience should be in responsible charge of works of importance and that some definite criterion or measure should be indicated as a reasonable guide for the Chief of Engineers in making details or appointments. We realize that within proper limits he should have opportunity for the exercise of his discretion, but it seems to us that some such provision as that indicated would relieve him from a responsibility which otherwise might under certain circumstances be at least embarrassing. The cases are extremely rare where experience and judgment in engineering work justifying the assignment of responsible duties have been acquired in less than five years.

"We recognize, however, that the officers of the Corps of Engineers have engineering experience in other constructions than those of river and harbor improvement. Much of the work on fortifications, for example, is engineering of a high order, and it would be well to broaden the language of the proposed amendment by substituting in the last line for the words 'river and harbor work' the words 'works of engineering construction.'

"During our hearing before your honorable Committee, attention was called to the fact that the proposed amendment contains no provision in regard to the rate of pay of assistant engineers having the relative rank of Captain or Major, and the opinion was expressed by one of our number that no reason was seen why the compensation as well as the responsibilties and obligations should not be the same as those of Officers of the Corps of Engineers performing like duties; this committee agrees with those expressions. The omission of specific mention in the proposed amendment was, however, intentional, our purpose being to leave this for the fair consideration and decision of the Chief of Engineers.

"This committee has given these features of the proposed conditions of service most careful consideration, and we fail to find that any confusion of responsibilities or of official grade, or other prejudicial result can flow from the provisions of the proposed amendment if they should be put into force. On the contrary we are convinced of their wisdom and that they would add materially to the efficiency of the service of the Engineer Corps, and correspondingly advance the interests of the administration of this branch of the Federal Government.

"Very respectfully,
"(Signed) Charles Macdonald, *Chairman*,
"S. Whinery,
"Wm. H. Burr,
"Frederic P. Stearns,
"Alfred Noble."

THE LICENSING OF CIVIL ENGINEERS

At the Society meeting of April 6th, 1910, the Secretary reported as follows:

At the meeting of the Society, March 16th, 1910, a telegram addressed to the Secretary from Hon. J. L. Raldiris was read, in which he asked the support of the Society for a Bill, which he had introduced in the New York Assembly, for the licensing of Civil Engineers. This Bill was, by request, read in full to the Meeting, and a resolution was adopted referring the whole matter to the Board of Direction, and instructing the Secretary to communicate at once with the Committee on Public Education, stating that action, and requesting that the consideration of the Bill be deferred until the Board could take the matter up and communicate with the Committee further.

President Bensel, Past-President Noble and Wm. H. Burr, M. Am. Soc. C. E., appeared before the Committee in Albany, and at the present time it is understood that the Bill referred to has been withdrawn temporarily, but that some Bill which provides for the licensing of Engineers will be presented later.

The matter was considered by the Board of Direction at a meeting held April 5th, and the following resolution was adopted:

"*Resolved,* That it is the sense of the Board that it is the duty of the American Society of Civil Engineers to use its influence in the proper formulation of all legislation by the General Government, or by any of the States of the Union, which affects the practice of Engineers; and the Board recommends the appointment by the Society of a Committee whose duty it shall be to formulate the general lines on which such legislation should be based, and that said Committee be requested to report at the next Annual Convention."

The subject was discussed at some length by the meeting, and the President was authorized to appoint a Committee (for the purposes set forth in the resolution of the Board) of five, of which he shall be Chairman; said Committee to report to the next Annual Convention.

The President subsequently appointed the following committee:

John A. Bensel, *Chairman,*
Wm. H. Burr,
Geo. W. Tillson,
James Owen,
Chas. Warren Hunt.

SEARCHES IN THE LIBRARY

In January, 1902, the Secretary was authorized to make searches in the Library, upon request, and to charge therefor the actual cost to the Society for the extra work required. Since that time many searches have been made, and bibliographies and other information on special subjects furnished.

The resulting satisfaction, to the members, who have made use of the resources of the Society in this manner, has been expressed frequently, and leaves little doubt that, if it were generally known to the membership that such work would be undertaken, many would avail themselves of it.

The cost is trifling compared with the value of the time of an engineer who looks up such matters himself, and the work can be performed quite as well, and much more quickly, by persons familiar with the Library.

In asking that such work be undertaken, members should specify clearly the subject to be covered, and whether references to general books only are desired, or whether a complete bibliography, involving search through periodical literature, is desired.

In reference to this work, the Appendix* to the Annual Report of the Board of Direction for the year ending December 31st, 1906, contains a summary of all searches made to that date.

PAPERS AND DISCUSSIONS

Members and others who take part in the oral discussion of the papers presented are urged to revise their remarks promptly. Written communications from those who cannot attend the meetings should be sent in at the earliest possible date after the issue of a paper in *Proceedings*. The issue of volumes of *Transactions* is dependent on the closing of discussions, and the co-operation of the membership in this matter is essential to the regular issue of each quarterly volume.

All papers accepted by the Publication Committee are classified by the Committee with respect to their availability for discussion at meetings.

Papers, which, from their general nature, appear to be of a character suitable for oral discussion, will be published as heretofore in *Proceedings*, and set down for presentation to a future meeting of the Society, and, on these, oral discussion, as well as written communications, will be solicited.

All papers which do not come under this heading, that is to say, those which, from their mathematical or technical nature, in the

* *Proceedings*, Vol. XXXIII, p. 20 (January, 1907).

opinion of the Committee, are not adapted to oral discussion, will not be scheduled for presentation to any meeting. Such papers will be published in *Proceedings* in the same manner as those which are to be presented at meetings, but written discussions, only, will be requested for subsequent publication in *Proceedings* and with the paper in the volumes of *Transactions*.

SUBSCRIPTION PRICE TO THE PUBLICATIONS OF THE SOCIETY

The following subscription rates have been fixed by the Board of Direction for the publications of the Society:

Proceedings, ten Numbers per annum, $8. Price for single numbers, $1.

Transactions, four Volumes per annum, $12. Price for single volumes, $4.

On the above prices there is a discount of 25% to members who desire extra copies of any of these publications, to Libraries, and to Book-dealers.

There is also an additional charge per annum, to cover foreign postage, of 75 cents for *Proceedings* and $1 for *Transactions*, or 8 cents and 25 cents, respectively, for single numbers.

A special subscription rate has been fixed by the Board for the *Proceedings* of the Society for the benefit of Students in Technical Schools. This rate is $4.50 per annum, and is available to any *bona fide* student of any technical school.

LOCAL ASSOCIATIONS OF MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

San Francisco Association

The San Francisco Association of Members of the American Society of Civil Engineers holds regular bi-monthly meetings, with banquet, and weekly informal luncheons. The former are held at 6 P. M., at the Fairmont Hotel, on the third Friday of February, April, June, August, October, and November, and also on the third Wednesday of December, the latter being the Annual Meeting of the Association.

Informal luncheons are held at 12.15 P. M. every Wednesday, and the place of meeting may be ascertained by communicating with the Secretary of the Association, E. T. Thurston, Jr., Assoc. M. Am. Soc. C. E., 623 Wells Fargo Building.

The by-laws of the Association provide for the extension of hospitality to any members of the Society who may be temporarily in San Francisco, and any such member will be gladly welcomed as a guest of the Association at any of the above meetings, if he will notify the Secretary that he is in San Francisco.

(Abstract of Minutes of Meeting)

February 18th, 1910.—The meeting was called to order; Franklin Riffle, President, in the chair; E. T. Thurston, Jr., Secretary; and present, also, 34 members and guests.

President Riffle read his Inaugural Address, which, on motion, was ordered printed and distributed to all members of the Society in the State.

The matter of the proposed coalition of the several Engineering Societies in San Francisco, particularly with respect to centralization of headquarters, was introduced by the Secretary, who read a letter from Otto von Geldern, M. Am. Soc. C. E., stating his attitude in regard to the matter. On motion the matter was referred to the Board of Directors, with instructions to consult with committees from other Societies, and to report at the next meeting.

A paper by A. Kempkey, Jr., Jun. Am. Soc. C. E. (now Assoc. M.), on "A Concrete Water Tower," was read, and the subject was discussed by Messrs. Adams, Bos, Couchot, Marx, Tower, and others.

Adjourned.

Colorado Association

(Abstract of Minutes of Meeting)

March 12th, 1910.—The meeting was called to order; H. S. Crocker, President, in the chair; H. J. Burt, Secretary; and present, also, 14 members and 1 guest.

The minutes of the February meeting were read and approved.

A letter from the Secretary of the Society was read, advising that the resolution requesting the appointment of a committee on "Wood Preservation," had been adopted by the Society, and would be considered at the meeting of the Board of Direction on April 5th, 1910.

The Secretary read a preliminary report of the Committee on Legislation, presented by George G. Anderson, M. Am. Soc. C. E. The chief items of this report were as follows: Proposal to transfer the internal revenue funds of the State from the Legislature to the State Highway Commission; revision of the legislation regarding the forming of drainage districts; payment of all Water Commissioners by the State; the establishing of State hydraulic survey; legislation regulating the practice of the profession of engineering.

Adjourned.

PRIVILEGES OF ENGINEERING SOCIETIES EXTENDED TO MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Members of the American Society of Civil Engineers will be welcomed by the following Engineering Societies, both to the use of their Reading Rooms and at all Meetings:

American Institute of Mining Engineers, 29 West Thirty-ninth Street, New York City.

Associação dos Engenheiros Civis Portuguezes, Lisbon, Portugal.

Australasian Institute of Mining Engineers, Melbourne, Victoria, Australia.

Boston Society of Civil Engineers, 715 Tremont Temple, Boston, Mass.

Brooklyn Engineers' Club, 117 Remsen Street, Brooklyn, N. Y.

Canadian Society of Civil Engineers, 413 Dorchester Street, West, Montreal, Que., Canada.

Civil Engineers' Society of St. Paul, St. Paul, Minn.

Cleveland Engineering Society, 718 Caxton Building, Cleveland, Ohio.

Cleveland Institute of Engineers, Middlesbrough, England.

Colorado Association of Members, Am. Soc. C. E., H. J. Burt, Secy., 235 Equitable Building, Denver, Colo.

Engineers' and Architects' Club of Louisville, Ky., 303 Norton Building, Fourth and Jefferson Streets, Louisville, Ky.

Engineers' Club of Baltimore, Baltimore, Md.

Engineers' Club of Minneapolis, 17 South Sixth Street, Minneapolis, Minn.

Engineers' Club of Philadelphia, 1317 Spruce Street, Philadelphia, Pa.

Engineers' Club of St. Louis, 3817 Olive Street, St. Louis, Mo.

Engineers' Club of Toronto, 96 King Street, West, Toronto, Ont., Canada.

Engineers' Society of Pennsylvania, 219 Market Street, Harrisburg, Pa.

Engineers' Society of Western Pennsylvania, 803 Fulton Building, Pittsburg, Pa.

Institute of Marine Engineers, 58 Romford Road, Stratford, London, E., England.

Institution of Engineers of the River Plate, Buenos Aires, Argentine Republic.

Institution of Naval Architects, 5 Adelphi Terrace, London, W. C., England.

Junior Institution of Engineers, 39 Victoria Street, Westminster, S. W., London, England.

Koninklijk Instituut van Ingenieurs, The Hague, The Netherlands.

Louisiana Engineering Society, 321 Hibernia Bank Building, New Orleans, La.

Memphis Engineering Society, Memphis, Tenn.

Midland Institute of Mining, Civil and Mechanical Engineers, Sheffield, England.

Montana Society of Engineers, Butte, Montana.

North of England Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne, England.

Oesterreichischer Ingenieur- und Architekten-Verein, Eschenbachgasse 9, Vienna, Austria.

Pacific Northwest Society of Engineers, 803 Central Building, Seattle, Wash.

Rochester Engineering Society, Rochester, N. Y.

Sachsischer Ingenieur- und Architekten-Verein, Dresden, Germany.

Sociedad Colombiana de Ingenieros, Bogota, Colombia.

Societe des Ingenieurs Civils de France, 19 Rue Blanche, Paris, France.

Society of Engineers, 17 Victoria Street, Westminster, S. W., London, England.

Svenska Teknologforeningen, Brunkebergstorg 18, Stockholm, Sweden.

Tekniske Forening, Vestre Boulevard 18–1, Copenhagen, Denmark.

Western Society of Engineers, 1737 Monadnock Block, Chicago, Ill.

ACCESSIONS TO THE LIBRARY

(From March 8th to April 11th, 1910)

DONATIONS*

DIAGRAMS FOR DESIGNING REINFORCED CONCRETE STRUCTURES.

Including Diagrams for Reactions and Strengths of Steel Beams. By G. F. Dodge. Boards, 13 x 15 in., illus., 8 + 104 pp. New York and Chicago, The Myron C. Clark Publishing Co.; London, E. & F. N. Spon, Ltd., 1910. $4.00.

In his diagrammatical treatment of this subject, the author's aim has been, it is stated, to offer a method of developing the greatest saving possible in the detail work of designing in reinforced concrete with exact formulas. Such a method, to be acceptable, he states, must be based on theoretically correct formulas and embody all the requirements of building ordinances of various localities; must be rapid and accurate in application; and if possible, must give at a glance the final result of changing any one or more of the assumed variabilities of design. A solution which he believes will fulfill all these requirements, is here offered. This book is intended to fill the needs of designing engineers and architects who are familiar with the nature of the materials used and with the theories of flexure entering into problems of design, and does not include an elementary treatise of the subject. The diagrams are constructed on partial or step solutions which are stated to be particularly adaptable to the complicated theoretical formulas of reinforced concrete. The solutions are said to be universal in their application in that they may be used to investigate the stresses under given loadings, or the carrying capacities of existing structures, as well as to design members for new construction. Four values of the ratio of moduli of elasticity, *n*, have been used, namely 12, 15, 18, and 30. The Contents are: Formulæ and Discussion: Straight Line Variation of Stress; Parabolic Variation of Stress, Ultimate Loads; Miscellaneous.

THE AMERICAN TRANSPORTATION PROBLEM.

A Study of American Transportation Conditions. By John Howe Peyton, M. Am. Soc. C. E. Second Edition. Paper, 9 x 6 in., illus., 13 + 311 pp. Louisville, Ky., Courier-Journal Job Printing Company, 1909. 50 cents. (Donated by the Author.)

In a secondary title it is stated that this study was made "with a view to ascertaining what policy Americans should adopt in order to effectively meet existing conditions and be prepared to continue to lead the nations in the march of progress and civilization." The author states that it is his impression that all the recent agitation for improving inland waterways is due to prejudice against railroads and a general lack of information as to actual transportation conditions on rivers and canals as well as on railroads, and while he has no hope that his investigations will have any effect in modifying the popular craze for inland waterways, he feels sure that a study of the data contained in this book will convince one that the commercial navigation of American inland waterways is economically impossible, no matter what may be expended on their improvement. The Contents are: The Relation Between Transportation and World Progress; Veins and Arteries of the Body Politic; Great Men vs. Demagogues; Inland Waterways; Reservoirs; Existing and Prospective Conditions; American Canals of Less Than Twenty Feet Depth; The Lakes-to-the-Gulf Deep Waterway (Chicago to the Gulf of Mexico); Current Arguments in Favor of Inland Waterways; Comparisons as to Speed and Efficiency; Comparisons with Traffic in Europe; Comparisons with Traffic on the Ohio River; Comparisons Between Railroad and Water Rates; Senator Knox's Pittsburg Address; The Lakes-to-the-Gulf Deep Waterway Again (Chicago to St. Louis); Mississippi River—St. Louis to the Gulf; The Upper Mississippi River; The Black Warrior River; The Columbia River and Some Other Inland Waterways; The Railroads; Conclusion.

FORMULAIRE DES CENTRAUX.

Résumé par Ordre Alphabétique des Cours et Projets de l'Ecole Centrale des Arts et Manufactures. Par J. P. Third Edition, Revised, Corrected, and Enlarged. Roan, 6 x 4 in., illus., 5 + 462 pp. Paris, H. Dunod et E. Pinat, 1910. 7 francs 50 centimes.

*Unless otherwise specified, books in this list have been donated by the publisher.

ANNUAIRE STATISTIQUE ET DESCRIPTIF DES DISTRIBUTIONS D'EAU

de France, Algérie, Tunisie et Colonies Françaises, Belgique, Suisse, et Grand-Duché de Luxembourg. Par MM. Imbeaux, Hoc, Devos, Van Lint Bétant, Peter, et Klein. Second Edition. Paper, 10 x 6½ in., illus., 40 + 1 550 pp. Paris, H. Dunod et E. Pinat, 1909. 25 francs.

The preface states that this book contains a history of the distribution and purification of the water supplies of cities and towns of the French speaking countries of Europe and Africa, and corresponds to the "Manual of American Water-Works" in the United States. For France, Algeria, and Tunis, cities and towns are arranged alphabetically under the Departments; for Belgium, the Grand Duchy of Luxembourg, and Switzerland, the arrangement is alphabetical by cities and towns. Under each place are given the population, date of installation of works, a short description of the water purification works and, sometimes, of the sewerage system, the cost of the works, and the name of the engineer; together with the sources of supply, method and rate of distribution, bacterial analysis. etc. The Contents are: Preface; France; Algérie et Tunisie; Colonies Françaises; Belgique; Grand-Duché de Luxembourg; Suisse; Tables Alphabétiques; Index Analytique des Annonces; Table Alphabétique des Annonces.

INSPECTOR'S HANDBOOK OF REINFORCED CONCRETE.

By Walter F. Ballinger, M. Am. Soc. C. E., and Emile G. Perrot, Assoc. M. Am. Soc. C. E. Cloth, 7 x 5 in., illus., 6 + 66 pp. New York, The Engineering News Publishing Co.; London, Archibald Constable and Company, Ltd., 1909. $1.00 net.

The authors, in publishing this small volume, hope, it is stated, to fill a place in the literature on reinforced concrete not covered by others. They also state that personal contact with inspectors and their view-points of various details of the work, convince them that such a book of instruction is necessary, and while they do not inform the inspector in regard to all his duties, they have endeavored to point out the essentials governing the construction of reinforced concrete buildings. The process of construction in actual work has been followed throughout the book, and an appendix which embraces formulas and tables to be used in calculating the strength of reinforced concrete, is included. The Contents are: Forms or Falsework; Reinforcement; Concrete; Appendix; Index.

MODERN COKING PRACTICE, INCLUDING THE ANALYSIS OF MATERIALS AND PRODUCTS.

A Handbook for Those Engaged in Coke Manufacture and the Recovery of Bye-Products. By T. H. Byron and J. E. Christopher. Cloth, 9 x 6 in., illus., 11 + 156 pp. New York, The Norman W. Henley Publishing Co.; London, Crosby, Lockwood and Son, 1910. $3.50 net.

This book is stated to be an amplification of a series of lectures delivered by one of the authors to a class of men engaged on coke ovens, and the authors hope that it will also prove useful and of benefit to those who are engaged in coke manufacture or who contemplate the laying down of a bye-product plant, the subject-matter having been kept up to date as nearly as possible. The Contents are: Introductory; General Classification of Fuels; Coal Washing; The Sampling and Valuation of Coal, Coke, etc.; The Calorific Power of Coal and Coke; Coke Ovens; Charging and Discharging of Coke Ovens; Cooling and Condensing Plant; Gas Exhausters; Composition and Analysis of Ammoniacal Liquor; Treatment of Waste Gases from Sulphate Plants; Valuation of Ammonium Sulphate; The Direct Recovery of Ammonia from Coke Oven Gases; Surplus Gas from Coke Ovens; Useful Tables; Index.

THE FIELD PRACTICE OF RAILWAY LOCATION.

By Willard Beahan, M. Am. Soc. C. E. Second Edition. Cloth, 9¼ x 6¼ in., illus., 9 + 254 pp. New York, The Engineering News Publishing Company, 1909. $3.00 net.

The first edition of this book was published in 1903. In the preface to the first edition, it is stated that the object of the book is to record the methods commonly used by American engineers in the West in the location of rail-

roads, built since the Civil War. The book is written from the standpoint of a chief of party, and is intended as an aid to men in a like position, to those who are about to make their first location, and to students. The nomenclature is that used in field work, and where the term is colloquial, quotation marks are used. The chapters, as well as the topics within each chapter, are arranged in the order in which problems of railroad location would naturally arise. A chapter is devoted to topography and much emphasis has been placed on reconnaissance work. The chapter on Locomotives contains only those elementary principles of locomotive design, proportion and capacity which a locating engineer must know. In this, the second edition, all known errors have been corrected, it is stated, and the book has been revised and rearranged. Corrections in units of railroading have been made wherever necessary. The Contents are: Preface; The Character of the Road; Reconnaissance for Route; Organization, Subsistence, and Equipment of Parties; Preliminary Survey; Geology in Its Relation to Topography; The Locomotive; Train Resistances; Cost and Capitalization; The Located Line; Records and Cost of Surveys; Appendix; Index.

HENLEY'S ENCYCLOPEDIA OF PRACTICAL ENGINEERING AND ALLIED TRADES, VOL. III-IV.

A Practical and Indispensable Work of Reference for the Mechanical Engineer, Designer, Draftsman, Shop Superintendent, Foreman, and Machinist. Edited by Joseph G. Horner, A. M. Inst. M. E. Half Morocco, 7½ x 9 in., illus. New York, The Norman W. Henley Publishing Co., 1907-08. $6 per vol., or $25 for set of 5 vol.

These volumes are but two of a set of five which comprise the whole work. It is stated that this publication which embraces the entire practice of civil and mechanical engineering, deals with the subject from the practical standpoint. The articles relating to the practice of various trades are stated to have been written by men who are familiar with the subject, and those which are treated mathematically, are discussed by men who combine practical experience with scientific training. The articles are said to be brief, yet clear and explicit statements of the subjects are made. The whole work is well illustrated with working drawings, diagrams, and photographs, and many cross-references are used to facilitate the work of those looking up any subject.

MUNICIPAL FRANCHISES.

A Description of the Terms and Conditions Upon Which Private Corporations Enjoy Special Privileges in the Streets of American Cities. Vol. I, Introductory: Pipe and Wire Franchises. By Delos F. Wilcox. Cloth, 8 x 6 in., 19 + 710 pp. Rochester, N. Y., The Gervaise Press; New York, Engineering News Book Department, 1910. $5.00 net.

In the preface to this, the first volume of this work, the author states that it is devoted to an analysis and description of municipal franchises as they exist in actual operation in American cities. Franchises for electric light and power, the telephone, telegraph, electrical signals, electrical conduits, water supply, sewerage, central heating, refrigeration, pneumatic tubes, oil pipe lines and artificial and natural gas, are discussed. In most cases a brief sketch is given of the history and importance of the utility and the special ways it is related to the city. This is followed by a description of typical franchises in actual operation in various cities of the United States. The second volume (to be issued later) is to be devoted to a discussion of the various classes of transportation and terminal franchises, and general observations and conclusions in regard to the taxation and control of public utilities. The Chapter Headings are: How Franchise Rights are Acquired; What a Franchise Signifies; Monopoly Profits, and Ways of Limiting Them; Injuries to Individuals, and Ways of Preventing Them; Temptations to Public Wrong, and Ways of Overcoming Them; Electric Light, Heat and Power as a Public Utility; Franchise Conditions Imposed on Electric Light and Power Companies; The Telephone; Telephone Franchise Regulations; The Telegraph and the Conditions Imposed Upon It by Local Authorities; Messenger and Signal Franchises; Electrical Conduits; Water-Works and Water Supply Franchises; Sewer Franchises; Central Heating Franchises; Refrigeration Franchises; Pneumatic Tubes and the Franchises Under Which They are Operated; Oil Pipe Line Franchises; Artificial and Natural Gas as Public Utilities; Gas Franchises Where Only Artificial Gas is Available; Gas Franchises in Cities Within Reach of Natural Gas Fields; List of Authorities; Index.

BRIDGE AND STRUCTURAL DESIGN.

By W. Chase Thomson. Second Edition. Cloth, 9½ x 6½ in., illus., 6 + 192 pp. New York, The Engineering News Publishing Company; London, Archibald Constable and Company, Limited, 1910. $2.00 net.

Although this book is intended principally for students and draftsmen, there are parts, it is stated, which may interest practicing bridge designers. It has been developed from lectures given by the author under the auspices of the Dominion Bridge Company, the object being to teach the elements of bridge and structural design in a simple and practical manner. In this edition, the author states, the subject-matter has been entirely re-written and the illustrations re-drawn, much that is new having been added. In the Contents, Articles 1 to 14 treat of general principles of design, and Articles 15 to 19 treat of typical structures in which the stresses are analyzed, the members proportioned, and the details carefully worked out. The remaining Chapter Headings are as follows: Example of Office Building Construction; The Design of a Simple Roof Truss; The Design of a Roof Truss Supported by Steel Columns; The Design of a Plate Girder; The Design of 50-foot Through Warren Girder Highway Bridge; The Design of a Pin-Connected Pratt Truss Highway Bridge; Coefficients for Stresses in Various Types of Trusses; Index.

Gifts have also been received from the following:

Am. Ry. Bridge and Bldg. Assoc. 1 vol.
Am. Street and Interurban Ry. Assoc. 2 pam.
Am. Water Works Assoc. 1 bound vol.
Andrews, H. B. 1 pam.
Baltimore, Md.-Harbor Board. 2 pam.
Barcroft, Frederick T. 1 bound vol.
Barschall, Max. 2 pam.
Bengal, India-Irrig. Dept. 1 vol., 1 pam.
Berlin Kgl. Technische Hochschule. 1 pam.
Boston, Mass.-Health Dept. 1 vol.
Brocton, Mass.-Water Commrs. 1 pam.
Brookline, Mass.-Water Board. 1 pam.
Burlington, Vt.-City Clerk. 1 vol.
Cal., Univ. of.-Univ. Press. 2 bound vol.
Cambridge, Mass.-City Messenger. 1 bound vol.
Camp, W. M. 1 vol.
Canada-Geol. Survey Branch. 1 pam.
Canada-Dept. of Marine and Fisheries. 1 bound vol., 4 plates.
Canadian Soc. of Civ. Engrs. 2 vol.
Cape of Good Hope.-Irrig. Branch. 2 pam.
Carns, Paul. 2 bound vol.
Chicago, Indiana & Southern R. R. Co. 1 pam.
Civ. Engrs.' Soc. of St. Paul. 1 pam.
Cleveland, Cincinnati, Chicago & St. Louis Ry. Co. 1 pam.
Compagnie du Congo pour le Commerce et l'Industrie. 1 pam.
Decimal Assoc. 3 pam.
Depew, Chauncey M. 1 pam.
Detroit, Mich.-Board of Water Commrs. 1 pam.
Eddy, Harrison P. 1 pam.
Eng. Soc. of Wis. 1 pam.
Engrs.' Club of New York. 1 bound vol.
Essex County, Mass.-County Engr. 1 pam.
Glasgow & South-Western Ry. Co. 1 pam.
Great North of Scotland Ry. Co. 1 pam.
Highland Ry. Co. 1 pam.
Holyoke, Mass.-Board of Water Commrs. 1 pam.
Illinois-State Geol. Survey. 1 bound vol.
Institution of Civ. Engrs. 1 bound vol.
Institution of Engrs. and Shipbuilders in Scotland. 1 bound vol., 1 pam.
Jackson, William. 12 bound vol., 11 pam.
Johnstown, N. Y.-Board of Water Commrs. 1 pam.
Kansas City-Western Ry. Co. 1 pam.
Kansas, Univ. of.-Eng. Exper. Station. 1 pam.
Kernot, Maurice E. 7 pam.
Lake Erie & Western R. R. Co. 1 pam.
Lake Shore & Mich. Southern Ry. Co. 1 pam.
Lehigh Univ. 1 vol.
Madras, India-Irrig. Branch. 1 bound vol.
Maine-State Commr. of Highways. 1 pam.
Maryland-Geol. and Economic Survey. 2 pam.
Mass.-Bureau of Statistics. 1 pam.
Mass.-R. R. Commrs. 1 bound vol.
Mich.-State Board of Health. 1 bound vol.
Mich. Central R. R. Co. 1 pam.
Mich. Eng. Soc. 2 bound vol.
Midland & South Western Junction Ry. Co. 1 pam.
Min. Soc. of Nova Scotia. 1 pam.
National Assoc. of Cotton Manufacturers. 1 bound vol.
New Bedford, Mass.-Water Board. 1 pam.
New Jersey-State Water Supply Comm. 1 pam.
New Jersey Sanitary Assoc. 1 pam.
New York-Board of *City Record.* 1 bound vol.
New York City-Dept. of Finance. 1 bound vol.
New York City-Health Dept. 2 bound vol.
New York City-Tenement House Dept. 1 bound vol.
New York State-Museum. 1 bound vol.

New York State-Public Service Comm., First Dist. 3 bound vol., 5 pam.
New York-State Dept. of Highways. 1 bound vol.
New York, Chicago & St. Louis R. R. Co. 1 pam.
New York City. Bureau of Municipal Research. 1 vol.
Newton, Mass.-Water Dept. 1 pam.
North British Ry. Co. 1 pam.
Oberlin Coll. Library. 1 pam.
Ohio-State Board of Health. 1 bound vol.
Ontario Canada-Provincial Board of Health. 1 vol.
Pennsylvania R. R. Co. 1 pam.
Pennsylvania, Univ. of. 1 vol.
Philadelphia, Pa.-Bureau of Surveys. 1 bound vol., 1 vol.
Philippine Islands-Bureau of Forestry. 1 pam.
President's Homes Comm. 1 vol.
Providence, R. I.-Dept. of Public Works. 1 pam.
Punjab, India-Irrig. Works. 1 bound vol.
Queensland, Australia-Water Supply Dept. 2 pam.
Reading, Mass.-Water Commrs. 1 pam.
Regia Universita' Romana. 1 vol.
Rhode Island-R. R. Commr. 1 bound vol.
Roadmasters' and M. of W. Assoc. of America. 1 pam.
Royal Soc. of New South Wales. 2 vol.
St. Louis Merchants Exchange. 1 vol.
St. Louis, Rocky Mountain & Pacific Co. 1 pam.
St. Paul, Minn.-Board of Water Commrs. 1 pam.
Salem, Mass.-Water Board. 1 pam.
San Francisco Assoc. of Members, Am. Soc. C. E. 1 pam.
São Paulo (State), Brazil-Commissão Geographica e Geologica. 4 vol., 1 pam., 24 maps.
Soc. of Ry. Club Secretaries. 1 pam.
Switzerland-Abteilung für Landeshydrographie. 1 vol.
Texas & Pacific Ry. Co. 1 pam.
Transvaal-Mines Dept. 1 vol.
U. S.-Bureau of Fisheries. 1 bound vol.
U. S.-Bureau of Insular Affairs. 1 bound vol.
U. S.-Bureau of Statistics. 3 pam.
U. S.-Bureau of the Census. 1 vol., 1 pam.
U. S.-Chf. of Engrs. 2 vol., 53 pam.
U. S.-Coast and Geodetic Survey. 1 bound vol.
U. S.-Dept. of Commerce and Labor. 1 bound vol.
U. S.-Geol. Survey. 2 bound vol., 15 pam.
U. S.-Interstate Commerce Comm. 1 vol., 6 pam.
U. S.-National Herbarium. 1 pam.
U. S.-Office of Exper. Stations. 2 pam.
U. S.-Office of the Library and Naval War Records. 1 vol., 2 pam.
U. S.-Public Health and Marine Hospital Service. 1 vol.
U. S. Steel Corporation. 1 pam.
Vermont, Univ. of. 1 vol.
Wellington, New Zealand-Harbour Board. 1 pam.
White, *Sir* William H. 1 pam.
Wilmington, Del.-Water Dept. 1 vol.
Winthrop & Co., Robert. 1 pam.
Yale Univ. Library. 1 bound vol.

BY PURCHASE

Air and Health. By Ronald Campbell Macfie. E. P. Dutton and Company, New York, 1909.

Vorlesungen über Ingenieur=Wissenschaften. By Georg Christoph Mehrtens. Part I, Vol. 2. Ed. 2, rev. and enl. Wilhelm Engelmann, Leipzig, 1910.

Repertorium der Technischen Journal-Literatur, Herausgegeben im Kaiserlichen Patentamt, 1908. Carl Heymanns, Berlin, 1909.

The Design and Construction of Internal=Combustion Engines; a Handbook for Designers and Builders of Gas and Oil Engines. By Hugo Güldner. Translated from the Second Revised Edition, with Additions on American Engines, by H. Diederichs. D. Van Nostrand Company, New York, 1910.

SUMMARY OF ACCESSIONS

(From March 8th to April 11th, 1910)

Donations (including 17 duplicates)	311
By purchase	4
Total	315

MEMBERSHIP

ADDITIONS

(March 9th to April 12th, 1910)

MEMBERS		Date of Membership.
BROSIUS, ALBERT MARSHALL. First Asst. Engr., Sewerage Comm. of Baltimore, 904 American Bldg., Baltimore, Md		Mar. 1, 1910
BURKE, HUBERT FRANCIS DAUBENEY. Director General de Obras Publicas, Santo Domingo City, Santo Domingo.		Feb. 1, 1910
GOETHALS, GEORGE WASHINGTON. Chairman and Chf. Engr., Isthmian Canal Comm., Culebra, Canal Zone, Panama		Mar. 1, 1910
HARWOOD, THOMAS TRIPLETT HUNTER. Asst. Engr., U. S. Engr. Office, 25 Pemberton Sq., Boston, Mass		April 5, 1910
HUMPHREYS, CLIFTON STEWART. Engr., (Snow & Humphreys) Madison, Me	Assoc. M. M.	May 2, 1900 April 5, 1910
LEWIS, WILLIAM WILLETT. Asst. Engr., Boston Transit Comm., 49 Oak St., Hyde Park, Mass		April 5, 1910
LOE, ERIC HALDORSON. Archt., and Engr., Russell Miller Milling Co., Minneapolis, Minn		Feb. 1, 1910
MACCALLA, CLIFFORD SHERRON. Asst. Gen. Mgr., The Washington Water Power Co., Spokane, Wash		Mar. 1, 1910
MACDIARMID, MILO STUART. Jun. Engr., U. S. Lake Survey, 215 Old Custom House, Detroit, Mich	Assoc. M. M.	Sept. 4, 1907 April 5, 1910
NOBLE, FREDERICK CHARLES. Div. Engr., Public Service Comm. for the First Dist., 4 Court Sq., Brooklyn, N. Y	Assoc. M. M.	June 4, 1902 Mar. 1, 1910
RAYMER, ALBERT REESOR. Asst. Chf. Engr., Pitts. & Lake Erie R. R. Co., Pittsburg, Pa		Mar. 1, 1910
SALAS, RAFAEL ALVAREZ. Gen. Mgr., Cauca R. R., Cali, Colombia		Jan. 4, 1910
SCHICK, JAMES REESE. Engr. of Branch Lines, Norfolk & West. Ry. Co., 915 Nelson St., Roanoke, Va		Mar. 1, 1910
SILLIMAN, CHARLES. Asst. Engr., Norfolk & West. Ry. (Res., 926 Nelson St.), Roanoke, Va		Mar. 1, 1910
SMITH, LAYTON FONTAINE. Engr. Representative, Trussed Concrete Steel Co., Wilson Bldg., Baltimore, Md	Assoc. M. M.	June 5, 1907 April 5, 1910
THOMPSON, ARTHUR WEBSTER. Chf. Engr., M. of W., B. & O. R. R. Co., B. & O. Bldg., Baltimore, Md	Assoc. M. M.	June 4, 1902 April 5, 1910
UHLER, WILLIAM DAVID. Second Asst. Engr., State Roads Comm., Care, Johns Hopkins Univ., Baltimore, Md	Assoc. M. M.	May 6, 1908 Mar. 1, 1910

MEMBERS (*Continued*).

		Date of Membership.
WADDELL, CHARLES EDWARD. Cons. Engr., 78 Patton Ave., Asheville (Res., Biltmore), N. C.		Mar. 1, 1910
WEIDMAN, WILLIAM ROE. 369 Williams Ave., Portland, Ore.		Feb. 1, 1910
WHITNEY, THOMAS BRYAN, JR. Engr. of Design, Hudson & Manhattan R. R., 30 Church St., New York City	Jun. Assoc. M. M.	Sept. 6, 1898 Feb. 6, 1907 April 5, 1910

ASSOCIATE MEMBERS

ALDERSON, WILLIAM HOWARD. Cons. Engr.'s Office, S. P. Co., Union Pacific System, 135 Adams St., Room 603, Chicago, Ill.	Jun. Assoc. M.	Dec. 5, 1905 Mar. 1, 1910
BECKER, ELVIN JAY. Asst. Engr., in Chg. of Constr., Contr. No. 11, Barge Canal, Waterford, N. Y.	Jun. Assoc. M.	April 3, 1906 Mar. 1, 1910
BINGHAM, CLARENCE ARMINGER. City Engr., Carlisle, Pa.	Jun. Assoc. M.	June 5, 1906 Jan. 4, 1910
BOUDE, PHILIP BETHEL. Asst. to Div. Engr., Philadelphia Terminal Div., P. R. R., Room 26, Thirty-second and Powelton Ave., Philadelphia, Pa.		Mar. 1, 1910
BULLEN, ROY. Hotel Fifth East, Salt Lake City, Utah	Jun. Assoc. M.	May 1, 1906 Mar. 1, 1910
CALDWELL, FRED EDWARD. Newton, N. J.	Jun. Assoc. M.	April 3, 1906 Feb. 1, 1910
DAY, WILLIAM PEYTON. Asst. Engr., John B. Leonard, 344 North Willard St., San Francisco, Cal.	Jun. Assoc. M.	Mar. 6, 1906 Mar. 1, 1910
EDWARDS, LLEWELLYN NATHANIEL. P. O. Box 362, Montreal, Que., Canada		Mar. 1, 1910
FERTIG, JEROME HENRY. Asst. Engr., U. S. Reclamation Service, Montrose, Colo.	Jun. Assoc. M.	Oct. 2, 1906 Mar. 1, 1910
FISK, ANDREW JACKSON, JR. Care, U. S. Reclamation Service, St. Ignatius, Mont.		Nov. 30, 1909
FORD, WILLIAM ELLIS. (Ford & MacCrea), Room 223, Gazette Bldg., Little Rock, Ark.		Mar. 1, 1910
HAMILL, WILLIAM SAMUEL. Care, Hudson Valley Constr. Co., Comstock, N. Y.		Mar. 1, 1910
HOLDEN, CHARLES ARTHUR. Prof. of Civ. Eng., Thayer School of Eng., Dartmouth Coll., Hanover, N. H.	Assoc. Assoc. M.	Nov. 1, 1905 Mar. 1, 1910
HOWE, CLARENCE DURAND. Asst. Engr., U. S. Reclamation Service, in Chg. Huntley Project, Huntley, Mont.		Feb. 1, 1910
HUBER, WALTER LEROY. Civ. Engr. for John Galen Howard, Archt., 604 Mission St., San Francisco, Cal.	Jun. Assoc. M.	April 3, 1906 Mar. 1, 1910

ASSOCIATE MEMBERS (*Continued*).

		Date of Membership.
IVES, HOWARD CHAPIN. Asst. Prof. of R. R. Eng., Worcester Polytechnic Inst., Worcester, Mass.	Jun. Assoc. M.	Dec. 3, 1901 April 5, 1910
KEMPKEY, AUGUSTUS, JR. 224 Mountain Ave., Piedmont, Cal.	Jun. Assoc. M.	Mar. 31, 1903 Feb. 1, 1910
KITTREDGE, HARRY CHANDLER. Care, Kittredge Concrete Co. (Res., 42 Werner Park), Rochester, N. Y.		Mar. 1, 1910
LANG, FRANK AUGUST. Asst. Supt. and Insp., U. S. Public Bldgs., Room 727, Custom House, New York City.		Mar. 1, 1910
LUDLOW, JUSTIN WYMAN. Asst. Prof. of Structural Eng., Lewis Inst., Chicago, Ill.	Jun. Assoc. M.	April 5, 1904 Mar. 1, 1910
MCNEIL, ARTHUR JAMES. P. O. Box 7, McKittrick, Kern Co., Cal.	Jun. Assoc. M.	Mar. 6, 1906 Mar. 1, 1910
MARTIN, WILLIAM FRANKLIN. Chf. Hydrographer, Territory of Hawaii, Dept. of Public Works, Honolulu, Hawaii.	Jun. Assoc. M.	Mar. 5, 1907 Feb. 1, 1910
MOORE, LEWIS EUGENE. Asst. Prof. of Civ. Eng., Mass. Inst. Tech., 85 Washington Park, Newtonville, Mass.	Assoc. Assoc. M.	April 1, 1908 April 5, 1910
NAVARRETE, SALVADOR MARIA, Avenida Morelos 25, Mexico City, Mexico.		Mar. 1, 1910
NOLAN, SIMON FRANK. Engr. in Bridge and Harbor Dept. of City Engr.'s Office, 103 Bernon St., Providence, R. I.		April 5, 1910
PLUMMER, HORACE EDWARDS. Engr., Office of Bldg. Insp., 497 East 27th St., Portland, Ore.	Jun. Assoc. M.	April 30, 1907 Feb. 1, 1910
RHODES, CLAUDE IRVIN. 366 Capp St., San Francisco, Cal.	Jun. Assoc. M.	Mar. 5, 1907 Mar. 1, 1910
ROACH, JAMES HOWARD. Div. Engr., L. S. & M. S. Ry. Co., Room 54, L. S. & M. S. Ry. Offices, Cleveland, Ohio.		April 5, 1910
SEARS, WALTON HARVEY. Div. Engr., Charles River Basin Comm., 367 Boylston St., Boston, Mass.		April 5, 1910
SHAW, GEORGE HERBERT. Asst. Engr., Met. Sewerage Comm. of New York, 142 Columbia Heights, Brooklyn, N. Y.		April 5, 1910
SNELL, JOSEPH EMMETT. 247 North 6th St., Newark, N. J.		April 5, 1910
WAITE, DONALD CRAMER. Asst. Engr., Interborough Rapid Transit Co., 165 Broadway (Res., 615 West 144th St.), New York City.	Jun. Assoc. M.	Jan. 3, 1905 April 5, 1910
WEIDNER, CARL ROBERT. Instr. in Hydr. Eng., Univ. of Wisconsin, 18 West Gilman St., Madison, Wis.	Jun. Assoc. M.	Feb. 28, 1905 April 5, 1910
WHEAT, GEORGE NEVILLE. P. O. Box 72, Station A, Houston, Tex.		Jan. 4, 1910

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WILSON, WILLIAM RENFREW. Care, Imperial Rys. of North China, Tientsin, North China	Jan. 4, 1910
WINSLOW, CARLILE PATTERSON. Care, Tenn. Coal, Iron & R. R. Co., Birmingham, Ala	Mar. 1, 1910

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ROWNTREE, BERNARD. (Burdett-Rowntree Mfg. Co.), 147 West 26th St., New York City	April 5, 1910

JUNIORS

BEARD, VIVIAN DANGERFIELD. Instr. in Civ. Eng. Dept. of Iowa State Coll., Station A, Ames, Iowa	April 5, 1910
BUSHWAY, WALTER BENJAMIN. 323 Broadway, Cambridge, Mass	Nov. 8, 1909
DAVIS, ROLAND PARKER. Instr. in Civ. Eng., Cornell Univ., Lincoln Hall, Cornell Univ., Ithaca, N. Y	Mar. 1, 1910
DAVISON, ALLEN STEWART. 300 Maple Ave., Swissvale Station, Pittsburg, Pa	Mar. 1, 1910
ENTEMANN, PAUL MAX. Asst. Engr., Public Service Comm., First Dist.; Address, 872 East 181st St., New York City	Mar. 1, 1910
FARRINGTON, HAROLD PHILLIPS. Care, Viele, Blackwell & Buck, 49 Wall St., New York City	April 5, 1910
GIBBLE, ISAAC OBERHOLZER. Care, Bartell & Ranney, Ave. C and Travis St., San Antonio, Tex	Nov. 8, 1909
HANEY, ALBERT PAUL. Tomkins Cove, N. Y	Nov. 8, 1909
HUFF, WALTER WILLIAM. 553 East 114th St., Cleveland, Ohio	Nov. 30, 1909
JORDAN, MYRON KENDALL. 523 East 18th Ave., Denver, Colo	Mar. 1, 1910
KITTREDGE, FRANK ALVAH. Res. Engr. for State Highway Dept. of Wash., 4130 Eleventh Ave., N. E., Seattle, Wash	Mar. 1, 1910
MCCAMPBELL, ALFRED KESSINGER. Care, Tech. School, Seczuen Province, Chentu, China, *via* Shanghai	Nov. 30, 1909
MCCLURE, HUNTER. 2802 Mountain Ave., Birmingham, Ala.	Jan. 4, 1910
MARSTON, FRANK ALWYN. Asst. Engr. with Metcalf & Eddy, Boston (Res., 6 Haley St., Roxbury), Mass.	Mar. 1, 1910
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OGIER, GEORGE RUFUS. Engr. and Contr. (Ogier, Silsbee & Ogier), 710 Majestic Bldg., Denver, Colo	Jan. 4, 1910
OKES, DAY IRA. Chf. Engr., The Kettle River Co., 405 Iowa Loan and Trust Bldg., Des Moines, Iowa	Mar. 1, 1910
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READ, BILL. 167 Washington Ave., San Jose, Cal........	Nov. 8, 1909
SCOTT, JAMES ROBINSON, JR. Draftsman, Bridge Dept., Ill. Cent. R. R. Co., Room 1000 Central Station, Chicago, Ill..................................	Mar. 1, 1910
STEINMAN, DAVID BERNARD. Instr. in Theory and Practice of Surveying, etc., City College; Address, 53 Seventh St., New York City............................	Mar. 1, 1910
STILSON, CHARLES EDWARD. Care, J. G. White & Co., Bayard, Nebr....................................	Mar. 1, 1910
TIMBERLAKE, SETH MARTIN. Cornwall-on-Hudson, N. Y....	Mar. 1, 1910
WARD, CHARLES HENRY, 2D. Middletown, R. I............	Oct. 5, 1909
WARNER, GLENN. Care, Office of Asst. to Pres., Cin., Hamilton & Dayton Ry. Co., Cincinnati, Ohio..........	Jan. 4, 1910
YARNELL, DAVID LEROY. Asst. Drainage Engr., U. S. Dept. of Agri. Drainage Investigations, O. E. S., Washington, D. C....................................	April 5, 1910

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ASSOCIATE MEMBERS

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BELCHER, WALLACE EDWARD. Structural Engr., H. M. Byllesby & Co., Inc., 218 La Salle St., Chicago, Ill.

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COLLINS, JOHN T. Res. Engr., River Div., N. Y. C. & H. R. R. R. Co., Highland Falls, N. Y.

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FREEMAN, MILTON HARVEY. Asst. Engr., Board of Water Supply, New York City, Stone Ridge, Ulster Co., N. Y.

GIBSON, WILLIAM LOANE. Engr. in Chg. Location and Constr., Bolivian Branches Ferrocarril Antofagasta á Bolivia, Oruro, Bolivia.

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GUSTAFSON, GUSTAF EDWARD. Bldg. Constr. Engr., Board of Education, 3748 Maple Sq. Ave., Chicago, Ill.

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HAGER, ALBERT BERTRAM. Secy., Fidelty Eng. & Inspecting Co., 30 Church St., New York City (Res., 36 Addison Ave., Rutherford, N. J.).

HALDEMAN, WALTER STANLEY, Box 833, Kansas City, Mo.

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HILDRETH, JOHN LEWIS, JR. Asst. Engr., in Chg. Sec. 4, Moodna Siphon, Board of Water Supply, Box 697, Cornwall-on-Hudson, N. Y.

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LOVE, ANDREW CAVITT. Gen. Supt., Beaumont Irrig. Co., Beaumont, Tex.

MCCLURE, JOHN CLARENDON. Engr., M. of W., Arizona Eastern R. R., Tucson, Ariz.

MCGONIGLE, CHARLES JOSEPH. Asst. Contr. Agt., Milliken Bros., Inc., 815 Chamber of Commerce Bldg., Portland, Ore.

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SCOTT, WILLIAM FRY. Dunville, Canada.

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TALLMAN, LEROY. Elmsford, N. Y.

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ASSOCIATE

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JUNIORS

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WRIGHT, THOMAS JUDSON, JR. Canebrake, McDowell Co., W. Va.

RESIGNATIONS.

MEMBERS	Date of Resignation.
HOOK, CHARLES ADDISON	Mar. 1, 1910
WEINHAGEN, FRED	April 5, 1910

JUNIORS	Date of Resignation.
BABCOCK, FRANKLIN	Mar. 1, 1910
MADIGAN, FRANCIS WILLIAM	Mar. 1, 1910

DEATHS

BROWN, LINUS WEED. Elected Member, June 7th, 1899; died March 7th, 1910.

ERDMANN, EARL EDWIN. Elected Junior, July 1st, 1909; died March 29th, 1910.

HASBROUCK, CHARLES ALFRED. Elected Associate Member, February 3d, 1892; Member, December 5th, 1894; date of death unknown.

Total Membership of the Society, April 12th, 1910, 5 405

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST

(March 8th to April 4th, 1910)

NOTE.—*This list is published for the purpose of placing before the members of the Society, the titles of current engineering articles, which can be referred to in any available engi ring library, or can be procured by addressing the publi d e address and price being given wherever possible.*

LIST OF PUBLICAT

In the subjoined list of articles, references a given by the number prefixed to each journal in this list:

(1) *Journal*, Assoc. Eng. Soc., 31 Milk St., Boston, Mass., 30c.
(2) *Proceedings*, Engrs. Club of Phila., 1317 Spruce St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Engrs., Monadnock Blk., Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Canada.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(8) *Stevens Institute Indicator*, Stevens Inst., Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 25c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 25c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c.
(14) *Engineering Record*, New York City, 12c.
(15) *Railway Age Gazette*, New York City, 15c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Electric Railway Journal*, New York City, 10c.
(18) *Railway and Engineering Review*, Chicago, Ill., 10c.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England, 25c.
(22) *Iron and Coal Trades Review*, London, England, 25c.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gas Light Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World*, New York City, 10c.
(28) *Journal*, New England Water-Works Assoc., Boston, Mass., $1.
(29) *Journal*, Royal Society of Arts, London, England, 15c.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales* de l'Assoc. des Ing. Sortis des Ecoles Spéciales de Gand, Brussels, Belgium.
(32) *Mémoires et Compte Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economiques des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(37) *Revue de Mécanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Proceedings*, Am. Inst. Elec. Engrs., New York City, 50c.
(43) *Annales des Ponts et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governors Island, New York Harbor, 50c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 8c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift*, Verein Deutscher Ingenieure, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Düsseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift*, Oesterreichischer Ingenieur und Architekten Verein, Vienna, Austria.
(54) *Transactions*, Am. Soc. C. E., New York City, $4.
(55) *Transactions*, Am. Soc. M. E., New York City, $10.

(56) *Transactions*, Am. Inst. Min. Engrs., New York City, $5.
(57) *Colliery Guardian*, London, England.
(58) *Proceedings*, Engrs.' Soc. W. Pa., 803 Fulton Bldg., Pittsburg, Pa., 50c.
(59) *Transactions*, Mining Inst. of Scotland, London and Newcastle-upon-Tyne, England.
(60) *Municipal Engineering*, Indianapolis, Ind., 25c.
(61) *Proceedings*, Western Railway Club, 225 Dearborn St., Chicago, Ill., 25c.
(62) *Industrial World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E., London, England.
(64) *Power*, New York City, 20c.
(65) *Official Proceedings*, New York Railroad Club, Brooklyn, N. Y., 15c.
(66) *Journal of Gas Lighting*, London, England, 15c.
(67) *Cement and Engineering News*, Chicago, Ill., 25c.
(68) *Mining Journal*, London, England.
(70) *Engineering Review*, New York City, 10c.
(71) *Journal*, Iron and Steel Inst., London, England.
(71*a*) *Carnegie Scholarship Memoirs*, Iron and Steel Inst., London, England.
(73) *Electrician*, London, England, 18c.
(74) *Transactions*, Inst. of Min. and Metal., London, England.
(75) *Proceedings*, Inst. of Mech. Engrs., London, England.
(76) *Brick*, Chicago, Ill., 10c.
(77) *Journal*, Inst. Elec. Engrs., London, England.
(78) *Beton und Eisen*, Vienna, Austria.
(79) *Forscherarbeiten*, Vienna, Austria.
(80) *Tonindustrie Zeitung*, Berlin, Germany.
(81) *Zeitschrift für Architektur und Ingenieurwesen*, Wiesbaden, Germany.
(83) *Progressive Age*, New York City, 15c.
(84) *Le Ciment*, Paris, France.
(85) *Proceedings*, Am. Ry. Eng. and M. of W. Assoc., Chicago, Ill.
(86) *Engineering-Contracting*, Chicago, Ill., 10c.
(87) *Roadmaster and Foreman*, Chicago, Ill., 10c.
(88) *Bulletin* of the International Ry. Congress Assoc., Brussels, Belgium.
(89) *Proceedings*, Am. Soc. for Testing Materials, Philadelphia, Pa.
(90) *Transactions*, Inst. of Naval Archts., London, England.
(91) *Transactions*, Soc. Naval Archts. and Marine Engrs., New York City.
(92) *Bulletin*, Soc. d'Encouragement pour l'Industrie Nationale, Paris, France.
(93) *Revue de Métallurgie*, Paris, France, 4 fr. 50.
(94) *The Boiler Maker*, New York City, 10c.
(95) *International Marine Engineering*, New York City, 20c.
(96) *Canadian Engineer*, Toronto, Canada, 15c.
(97) *Turbine*, Berlin, Germany, 1 Mark.
(98) *Journal*, Engrs. Soc. Pa., 219 Market St., Harrisburg, Pa., 30c.
(99) *Proceedings*, Am. Soc. of Municipal Improvements, New York City, $1.
(100) *Professional Memoirs*, Corps of Engrs., U. S. A., Washington, D. C., $1.
(101) *Metal Worker*, New York City, 10c.

LIST OF ARTICLES

Bridges.

Some Features in the Design and the Construction of the Manhattan Suspension Bridge.* John C. Ostrup, M. Am. Soc. C. E. (5) Jan., 1909.
The Substructure of the P. & L. E. R. R. Bridge over the Ohio River at Beaver, Pa.* A. R. Raymer. (58) Feb.
Deflection Tests of Railway Bridges.* Conrad Gribbie, A. M. I. C. E. (10) Mar.
Strengthening of Railway Bridges in America.* George Sherwood Hodgins. (10) Mar.
The Atbara Bridge. (12) Mar. 11.
The Oak Point Float Bridges on the East River.* (14) Mar. 12.
A Reinforced-Concrete Arch Highway Bridge in Indiana Wrecked by Erosion of Foundations.* (13) Mar. 17.
Report on Temporary Trestling. Francis Dawson. (Paper read before the Nova Scotia Soc. of Engrs.) (96) Mar. 18.
The Shepherdstown Viaduct, Norfolk & Western Railway.* (14) Mar. 19.
Short-Span Single-Track Concrete Arch Bridges.* (14) Mar. 19.
A Reinforced Concrete Sewer Bridge.* Henry Ryon. (14) Mar. 26.
Different Methods of Erecting Steel Viaducts.* Frank W. Skinner, M. Am. Soc. C. E. (14) Apr. 2.
The East Olive Avenue Bridge in Spokane, Wash. (14) Apr. 2.
Piers of the Penhorn Creek Railroad Viaduct.* (14) Apr. 2.
Erection of Florida East Coast Railway Bridges.* (14) Apr. 2.

*Illustrated.

Bridges—(Continued).

The Erection of Tinkers Creek Viaduct.* (14) Apr. 2.
The Passyunk Avenue Bridge Piers.* (14) Apr. 2.
Widening Piney Creek Bridge, Washington.* (14) Apr. 2.
Oak Point Float Bridge Substructure Construction.* (14) Apr. 2.
Erection of the Slatington Bridge.* (14) Apr. 2.
Note sur la Construction du Viaduc des Fades (Ligne de Saint-Eloy à Volvic).* Virard. (43) Jan.
Notice sur les Travaux de Construction du Pont de Montanges. F. Lefort. (43) Jan.
Expériences sur le Pivot d'Essai du Pont Tournant sur l'Etang de Caronte (Ligne de Miramas à l'Estaque).* E. Chartiée et G. Blot. (38) Mar.
Le Viaduc Métallique sur la Vistule à Marienwerder (Prusse orientale).* (33) Mar. 5.

Electrical.

The Use of Aluminum as a Conductor. Julian C. Smith. (5) Jan., 1909.
The Tungsten Lamp, and its Behaviour on Life Tests as Compared with Carbon Lamps.* H. D. Burnett. (5) Jan., 1909.
The Oscillograph.* J. A. Johnson. (5) Jan., 1909.
Synchronism.* R. H. Mulock. (5) Jan., 1909.
Wireless Telegraph and Telephony.* Cornelius D. Ehret. (2) Jan.
Underground Conduit.* Paul W. England. (2) Jan.
Some Notes on Telephone Engineering. Nathan Hayward. (98) Feb.
Inaugural Address. (State of Electrical Engineering.)* Gisbert Kapp. (77) Feb.
The Present Aspect of Electric Lighting. H. W. Handcock and A. H. Dykes. (77) Feb.
The Electric Ignition of Internal Combustion Engines. John W. Warr. (77) Feb.
Some Experiments on Single and Stranded Low-Tension Fuses.* William Tolmé Maccall. (77) Feb.
Research on Metallic Filament Lamps.* F. H. Reakes Lavender. (77) Feb.
The Relation Between the Stator and Rotor Circuits of the Single-Phase Induction Motor.* Charles F. Smith. (77) Feb.
The Production, Measurement, and Effect of Variable Wave-Form.* Lancelot W. Wild. (77) Feb.
Experimental Determination of the Moment of Inertia of a Continuous-Current Armature.* Gisbert Kapp. (77) Feb.
The Theory of the Dynamometer Wattmeter.* Charles V. Drysdale. (77) Feb.
Central Stations for Towns of 1 000 Population. Caryl D. Haskins. (60) Mar.
Electrical Driving Installation at the Bannerman Mill Co.'s Brunswick Mill, Manchester.* (26) Mar. 4.
The Radiation from Directive Aerials in Wireless Telegraphy.* W. H. Eccles. (73) Mar. 4.
The Collins Long-Distance Wireless Telephone.* William Dubilier. (73) Mar. 4.
The Equipment of the Electrical Engineering Laboratories at the Brighton Technical College. H. H. Broughton. (73) Mar. 4.
Electric Welding.* (22) Mar. 4.
A British Electrically-Equipped Textile Mill.* James L. Doran. (27) Mar. 10.
Comparative Costs of Electric and Gasoline Soldering. William J. Miskella. (27) Mar. 10.
Post Office Telephone Cables.* O'Meara. (Abstract of paper read before the Physical Soc.) (73) Mar. 11.
Armature Reaction and Compounding of Alternators.* J. E. Dalemont and L. A. Herdt. (73) Mar. 11.
Alloys of Electrolytic Iron with Arsenic and Bismuth. C. F. Burgess and J. Aston. (Abstract of paper read before the Am. Electro-Chemical Soc.) (73) Mar. 11.
Quartz-Tube, Mercury-Vapor Lamps.* Warren H. Miller. (27) Mar. 17.
Voltage Regulation of Stationary Transformers.* E. H. Acton. (27) Mar. 17.
The Palmer Physical Laboratory.* Howard McClenahan. (27) Mar. 17.
Commonwealth Edison Company to Build Two New 120 000-Kw. Generating Stations with 20 000-Kw. Units.* (27) Mar. 17.
Electric Generating Installation for the Panama Canal.* (27) Mar. 17.
The Uses of Ozone: The Ozonair System.* (26) Mar. 18.
Steamship Repairs by Electric and Autogenous Welding.* A. Scott Younger. (Abstract of paper read before the Inst. of Engrs. and Shipbuilders in Scotland.) (73) Mar. 18.
Distribution System of the Southern Power Company.* J. W. Fraser. (27) Mar. 24.
Operations of Hydroelectric Plants. Alton D. Adams. (27) Mar. 24.
Elementary Electrical Engineering. L. W. Gill. (96) Serial beginning Mar. 25.
Aeronautics and Electricity. H. Thurn. (19) Mar. 26.

*Illustrated.

Electrical – (Continued).

Commutation, a Discussion of Resistance and Reactance of Coil Circuits during the Commutating Period.* F. W. Carter. (27) Mar. 31.
Joint Navy and Fessenden Long-Distance Wireless Tests.* (27) Mar. 31.
"Reasonable Rates" for Gas and Electricity as Determined by the Wisconsin Railroad Commission for the City of Madison. (13) Mar. 31.
The Developed High Tension Net-Work of a General Power System. Paul M. Downing. (42) Apr.
Lightning Protection.* Percy H. Thomas. (42) Apr.
Note sur les Enroulements des Induits pour Dynamos à Courant Continu.* O Steels. (31) 1909, Pt. 4.

Marine.

A Self-Dumping Barge.* A. F. Wiking. (13) Mar. 10.
The Latest French Torpedo-Boat Destroyers.* (12) Mar. 11.
New Type of Ore Carrying Steamer.* (12) Mar. 18.
Impulse Marine Turbines in Germany.* (12) Mar. 18.
The International Aero and Motor-Boat Exhibition.* (11) Serial beginning Mar. 18; (12) Serial beginning Mar. 18.
Fuel Oil. E. N. Percy. (95) Serial beginning Apr.
A New Form of Turbine Drive for Ship Propulsion.* (95) Apr.
The New River Steamers *City of Philadelphia* and *City of Wilmington*.* (95) Apr.
Gasoline Petrol Launch for the Isthmian Canal Commission. Stephen P. M. Tasker. (95) Apr.
Calculations for the Size of a Pump Beam.* Edward M. Bragg. (95) Apr.
Danish Petroleum and Crude Oil Motors.* Axel Holm. (95) Apr.
The New Dry-Dock of the Toledo Shipbuilding Company.* Harry C. McClure. (14) Apr. 2.
Note sur les Travaux d'Allongement du Bassin de Castigneau à l'Arsenal de Toulon.* Maroger. (43) Jan.
Recherches sur la Resistance à la Traction des Bateaux: Mesures des Vitesses au Moyen d'un Hydrocinémomètre Enregistreur, Basé sur le Principe du Tube de Pitot.* Clerc. (43) Jan.

Mechanical.

A Typical Case of a Successful Competition of Fleming Harrisburg Four Valve Engine vs. Corliss Engine.* Benj. T. Allen. (98) Jan.
The Relation of the Steam Turbine to Modern Central Station Practice.* G. R. Parker. (Paper read before the Engrs.' Club of St. Louis.) (1) Feb.
The Powering of Boiler Shops.* D. S. Downs.* (94) Mar.
Compressed Air for Pneumatic Hammers.* (94) Mar.
Specifications for Steel Boiler Tubes and Safe Ends. (Pennsylvania Railroad.) (94) Mar.
Electric Motor Drives for Machine Shops.* George W. Cravens. (41) Mar.
The Modern Pattern Shop.* George F. Reinhard. (Paper read before the Chicago Foundrymen Foremen.) (41) Mar.
Pressure-Raising Plant at Tynemouth.* William Hardie, Assoc. M. Inst. C. E. (66) Mar. 1.
The Stability of Flying Machines.* Herbert Chatley. (11) Serial beginning Mar. 4.
Commercial Vehicles at Manchester Motor Show. (47) Serial beginning Mar. 4.
Steel Foundry Practice. Percy Longmuir. (Paper read before the Manchester Assoc. of Engrs.) (47) Mar. 4.
Experiences with Semi-Vertical Retorts and Notes on Carbonizing Systems and Results.* Alfred T. Harris. (Paper read before the Midland Assoc. of Gas Mgrs.) (66) Mar. 8.
Electric Driving of Textile Mills.* (From *Vulcan*.) (47) Mar. 11.
Coal-Leveling Machine for Beehive Ovens.* (16) Mar. 12.
Sulphur Compounds in Illuminating Gas, with Particular Reference to the Testing for Hydrogen Sulphide.* Chas. J. Ramsburg. (Paper read before the Am. Gas Inst.) (24) Serial beginning Mar. 14.
Practical Applications of Illuminating Engineering.* Norman Macbeth. (Paper read before the Am. Gas Inst.) (83) Mar. 15.
A Commercial Fuel Briquette Plant, the Operations of the Solvay Process Company and the Semet-Solvay Company at Detroit, Mich.* W. H. Blauvelt. (20) Mar. 17.
Merchants Heat and Light Company; Application of the Steam Turbine for Lighting and Exhaust Steam Heating at Indianapolis, Ind.* (27) Mar. 17.
Shrinkage and Forced Fits and the Stresses They Produce.* A. Lewis Jenkins. (13) Mar. 17.
The International Aero and Motor-Boat Exhibition.* (11) Serial beginning Mar. 18; (12) Serial beginning Mar. 18.

*Illustrated.

Mechanical—(Continued).

The Diseases of Boilers. (14) Mar. 19.
An Improved Multiple Ammonia Washer.* (24) Mar. 21.
Meeting the Gas Demands of Bromley and Crays.* (66) Mar. 22.
1 500-Brake-Horse-Power High-Speed Steam-Engines.* (11) Mar. 25.
Possible Uses of Waste-Gas Power.* I. V. Robinson. (47) Mar. 25.
Weaving Appliances.* Frank Nasmith. (Paper read before the Manchester Assoc. of Engrs.) (47) Serial beginning Mar. 25.
Portable Rock Crushing and Concrete Mixing Plant.* (18) Mar. 26.
A Rapid Method for the Identification of Gas Oils. F. E. Park and L. E. Worthing. (Paper read before the Am. Gas Inst.) (24) Mar. 28.
Johnson and Johnson's New Power Plant.* Warren O. Rogers. (64) Mar. 29.
"Reasonable Rates" for Gas and Electricity as Determined by the Wisconsin Railroad Commission for the City of Madison. (13) Mar. 31.
Electric Drive in Textile Mills.* Albert Milmow. (42) Apr.
Gas Engines in City Railway and Lighting Service.* E. D. Latta, Jr. (42) Apr.
The Fuel-Briquetting Industry.* Charles L. Wright. (9) Apr.
Emergency Generating Stations for Service in Connection with Hydroelectric Transmission Plants Under Pacific Coast Conditions. A. M. Hunt. (42) Apr.
Single Unit Lighting Installations. Benjamin J. Bean. (Paper read before the New England Assoc. of Gas Engrs.) (83) Apr. 1.
Calorific Value of Gas in Wisconsin Cities. C. F. Burgess and W. J. Huddle. (Paper read before the Ill. Gas Assoc.) (83) Apr. 1.
Oiling Methods, Oils and Diaphragms for Meters.* R. B. Acker and C. C. Hotchkiss. (Paper read before the Ill. Gas Assoc.) (83) Apr. 1.
Aeroplane Stability, Some New Theories. G. H. Bryan. (19) Apr. 2.
New Crushing Plants of the Casparis Stone Company.* (14) Apr. 2.
Power Plants for Gas Works of Medium Size. Chas. D. Robinson. (Paper read before the Am. Gas Inst.) (24) Apr. 4.
L'Industrie des Ciments Portland de Grappiers et Chaux Hydrauliques.* H. Laborbe. (32) Dec.
La Turbine à Vapeur Zoelly.* (33) Feb. 26.
Automobile à Patins pour la Circulation sur la Niege.* E. Girardault. (33) Mar. 5.
La Fabrication du Benzol.* A. Grebel. (33) Mar. 19.

Metallurgical.

Drying Blast with Calcium Chloride.* (22) Mar. 11.
Recent Patents for Basic-Lined Copper Converters.* Richard H. Vail. (16) Mar. 12.
Midvale Blast Furnace Practice.* Leroy A. Palmer. (45) Apr.
The Washoe Reduction Works in 1909.* (45) Apr.
La Réduction des Minerais de Fer au Four Electrique. (33) Mar. 5.

Mining.

Electric Signalling Apparatus for Winding.* (22) Mar. 4.
Air Compressor Accidents in the Transvaal. (Abstract from Annual Report, Govt. Min. Engr.) (13) Mar. 17.
Rules for the Installation and Use of Electricity in Mines. Eustace E. Baker. (Paper read before the Manchester Geol. and Min. Soc.) (57) Mar. 18.
Operations of the Doe Run Lead Company.* Albert H. Fay. (16) Mar. 19.
Electric Mine Hoists.* D. B. Rushmore and K. A. Pauly. (42) Apr.
Filbert Mine Concrete-Lined Shaft.* A. F. Allard and Herbert S. Patterson. (45) Apr.
Novel Automatic Switch.* C. S. Beach. (45) Apr.
Cobalt Hydraulic Air Compressor.* C. H. Taylor. (45) Apr.
Mine Drainage in Joplin District.* Lucius L. Wittich. (45) Apr.
Wet Concentration at Midvale, Utah.* Leroy Palmer. (45) Apr.
Method of Square Set Stoping at Bisbee.* Morris J. Elsing. (16) Apr. 2.
The Ashokan Reservoir Stone Quarry.* (14) Apr. 2.

Miscellaneous.

Reforestation of the Marginal Lands of the Wachusett Reservoir of the Metropolitan Water Works, Boston, Mass.* E. R. B. Allardice. (Paper read before the Boston Soc. of Civ. Engrs.) (1) Jan.
On the Use of the Flicker Photometer for Differently Coloured Lights.* H. Morris-Airey. (77) Feb.
Commercial Sodium and Potassium Cyanide. W. J. Sharwood. (16) Mar. 19.
Education for Leadership in Electrical Engineering. Samuel Sheldon. (42) Apr.
Orgues en Ciment Armé. (From *Cement Age.*) (84) Feb.
Les Déplacements Quotidiens du Sommet de la Tour Eiffel.* E. Bret. (33) Mar. 12.

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*Illustrated.

Municipal.

Some Experiments on the Resistance of Pavements.* A. C. D. Blanchard. (5) Jan., 1909.

Relative Efficiency of the Day-Labor and Contract Systems of Doing Municipal Work. Harrison P. Eddy. (Paper read before the Boston Soc. of Civ. Engrs.) (1) Jan.

Asphaltic Treatment of Macadam Roads. Charles H. Bartlett. (Paper read before the Engrs.' Soc. of Milwaukee.) (1) Feb.

Data on Street Cleaning in St. Louis, Mo. (86) Mar. 9.

Reports on Specifications for Paving. (Report to the Convention of City Engrs. and Municipal Officials.) (13) Mar. 10; (86) Serial beginning Mar. 9.

Preparation and Use of Road Metal. A. McG. Rankin. (Paper read before the Ontario Good Roads Assoc.) (96) Mar. 11.

Experimental Work of the New York State Highway Commission. (14) Mar. 12.

Recent Work of the Brooklyn Municipal Asphalt Plant. (14) Mar. 12; (86) Mar. 16.

Method and Cost of Constructing a Shell-Macadam Pavement at Annapolis, Md. (86) Mar. 16.

Specifications for Concrete Sidewalks, Curbs and Street Pavements. (Paper read before the Organization for Standardizing Paving Specif.) (13) Mar. 17; (60) Apr.

Specifications for Bituminous Concrete Paving. (Paper read before the Organization for Standardizing Paving Specif.) (13) Mar. 17; (86) Mar. 23; (60) Apr.

Cost Data of Road Building. C. R. Wheelock. (Paper read before the Good Roads Assoc.) (96) Mar. 18; (86) Mar. 30.

Some Methods and Costs of Oiling Roads in St. Louis, with a Description of a New Construction Employing Molded Slabs of Bitumen and Aggregate.* (86) Mar. 23.

Cost of Patching Asphalt Pavement at St. Augustine, Fla., Using a Portable Repair Plant. (86) Mar. 30.

A Road Roller with New Front Truck Arrangement and Improved Details.* (86) Mar. 30.

Method and Cost of Snow Removal in St. Louis, Mo., by Flushing It Through City Sewers.* (86) Mar. 30.

Effect of Motor and Horse Traffic on Macadam Roads. Logan W. Page. (86) Mar. 30.

Heavy Regrading by Means of Hydraulic Sluicing at Seattle, Wash.* Geo. Holmes Moore. (13) Mar. 31.

Specifications for Creosoting Wood Block Pavement. (Report of Comm. Organization for Standardizing Paving Specif.) (13) Mar. 17; (86) Mar. 23;

A Comparison of Cost and Efficiency of Methods of Street Lighting. N. R. Birge. (From *General Electric Review.*) (60) Apr.

Specifications for Sheet Asphalt Pavement. (Report of Asphalt Comm., Organization for Standardizing Paving Specif.) (60) Apr.

Tar Macadam Roads.* F. E. Newberry. (Paper read before the Ill. Gas Assoc.) (83) Apr. 1.

Tar as Applied to the Surface Treatment of Roads. Hervey J. Skinner. (Paper read before the Am. Gas Inst.) (83) Apr. 1.

Railroads.

Railway Construction Notes.* F. Pardoe Wilson. (5) Jan., 1909.

Preservative Treatment in Relation to Cross-Tie Supply. E. A. Sterling. (98) Jan.

Report on the Use of Steel (America); Subject for Discussion at the Eighth Session of the Railway Congress.* D. F. Crawford. (88) Feb.

Report on Improvements in Locomotive Boilers (America); Subject for Discussion at the Eighth Session of the Railway Congress.* H. H. Vaughan. (88) Feb.

Report on Steam Locomotives for Very High Speed (America); Subject for Discussion at the Eighth Session of the Railway Congress.* Wm. Garstang. (88) Feb.

Report on Long Railway Tunnels, Construction, Ventilation and Operation (Submarine Tunnels); Subject for Discussion at the Eighth Session of the Railway Congress.* Felix Sartiaux. (88) Feb.

Report on Junctions and Swing-Bridges, Elimination of Slacking (France, Italy, Spain, and Portugal); Subject for Discussion at the Eighth Session of the Railway Congress.* F. Tettelin and M. Cossmann. (88) Feb.

Report on Long Railway Tunnels, Construction, Ventilation and Operation (Tunnels in Mountainous Countries, the Alps Excepted, and Great Town Tunnels, Great Britain Excepted); Subject for Discussion at the Eighth Session of the Railway Congress.* Canat. (88) Feb.

*Illustrated.

Railroads—(Continued).

Report on Large Stations (All Countries except America, Russia, Austria-Hungary, Roumania, Bulgaria, Servia and Turkey); Subject for Discussion at the Eighth Session of the Railway Congress.* Jullien and Leverve. (88) Feb.
Report on Long Railway Tunnels, Construction, Ventilation and Operation (Alpine Tunnels); Subject for Discussion at the Eighth Session of the Railway Congress.* F. Hennings. (88) Feb.
Points and Crossings for the North-Western (Indiana State) Railway.* (21) Mar.
Cylinder Proportions of the New P. L. M. Locomotives. Charles R. King. (21) Mar.
The Seasoning and Preservative Treatment of Wooden Cross-Ties.* F. J. Angier. (65) Mar.
Modern High-Speed Locomotives, Current American Practice.* J. F. Cole. (10) Mar.
Promotion of Safety in the Transportation of Explosives and Other Dangerous Articles in the United States. B. W. Dunn. (3) Mar.
Development of the Mallet Locomotive.* Grafton Greenough. (3) Mar.
Railway Fuel Supply.* Raffe Emerson. (10) Mar.
The Equipment of Railway Workshops, Current British Practice* G. H. Burrows, A. M. Inst. M. E. (10) Mar.
Mountain and Rack Railways.* Roman Abt. (10) Mar.
British Express Locomotives.* John Farquharson M'Intosh. (10) Mar.
River Tunnels at New York.* J. F. Springer. (10) Mar.
Some Recent Designs of Locomotives for Service on Continental Railways.* Albert H. Bone. (10) Mar.
Oil Burning on Freight Locomotives.* H. B. MacFarland. (10) Mar.
The Development and Design of the Electric Locomotive.* Theodore Rich. (10) Mar.
Car Wheels.* George L. Fowler. (10) Mar.
Railway Signaling in America.* J. S. Hobson. (10) Mar.
Power Railway Signaling, Current British Practice.* J. F. Gairns. (10) Mar.
Hydraulic Flanging of Locomotive Boiler Plates.* J. W. Margetts. (Abstract of paper read before the Swindon Eng. Soc.) (21) Mar.
The Riegler Ferro-Concrete Sleeper.* (21) Mar.
New Cape Central Railway.* (21) Mar.
An Experimental Mallet Articulated Locomotive, Canadian Pacific Railway.* G. I. Evans. (25) Mar.
Steel and Reinforced-Concrete Sleepers in the United States.* (11) Mar. 4.
New Rules for Computing Train Resistance. (13) Mar. 10.
A Locomotive with the Cab over the Pilot.* (13) Mar. 10.
Luminous Repeating or Advance-Indicating Railway Signals.* (13) Mar. 10.
The Trans-Continental Railway of Australia.* (11) Mar. 11.
The Alberta and Great Waterways Railways. (96) Mar. 11.
Subaqueous Tunnels.* R. B. Woodworth. (Paper read before the Railway Club of Pittsburgh.) (15) Serial beginning Mar. 11.
The Oak Point Float Bridges on the East River.* (14) Mar. 12.
Cast-Iron and Steel Wheels Discussed at Hartford.* (17) Mar. 12.
Unit Movements at Terminal Stations.* H. McL. Harding. (14) Mar. 12.
Construction of the Western Pacific Ry.* (18) Mar. 12.
Forestry Work of the A. T. & S. F. Ry.* (18) Mar. 12.
All-Steel Baggage Cars for Subway Service.* (15) Mar. 18; (17) Mar. 19.
The Pre-Cooling Plant of the Southern Pacific at Roseville, Cal.* (15) Mar. 18.
Track Elevation of the Chicago Terminal Transfer R. R.* (18) Mar. 19.
Sleeping Cars of Radically New Design for the Illinois Traction System.* (17) Mar. 19.
The Books of the Locomotive. Lawford H. Fry. (12) Mar. 25.
Cullybackey Interlocking and Tyer's Tablet.* (15) Mar. 25.
Multiple Unit Trains on the New Haven Railroad.* (17) Mar. 26.
Permanent City Track Construction for Interurbans.* H. L. Weber. (Abstract of paper read before the Central Elec. Ry. Assoc.) (17) Mar. 26.
New Electric Locomotives, B. & O. R. R.* (18) Mar. 26.
Mallet Articulated Locomotives for the Great Northern Ry.* (18) Mar. 26.
Steel Car Construction. C. R. Harris. (Abstract of paper read before the New England R. R. Club.) (18) Mar. 26.
Car Lighting by Electricity. J. R. Sloan. (Abstract of paper read before the Central Ry. Club.) (18) Mar. 26.
Cost of Constructing a Reinforced Concrete Fence Around a Shaft Top. (Pennsylvania R. R. Tunnel at Weehawken).* (86) Mar. 30.
A Railroad Shop's Crane Equipment.* (20) Mar. 31.
The Electric Storage Battery Locomotive.* Warren H. Miller. (27) Mar. 31.
Railway and Engineering Progress in Africa.* J. Hartley Knight. (9) Apr.

* Illustrated.

Railroads—(Continued).

The 1 200-Volt Railroad, a Study of Its Value for Interurban Railways.* Charles E. Eveleth. (42) Apr.
Mallet Articulated Compound Locomotive, New York Central Lines.* (15) Apr. 1.
The Disinfecting of Passenger Coaches. P. Schumacher. (From *Annalen für Gewerbe- und Bauwesen.*) (15) Apr. 1.
Car Wheel Foundry and Practice, Chicago, Milwaukee & St. Paul Railway.* Geo. L. Fowler. (15) Apr. 1.
Oak Point Float Bridge Substructure Construction.* (14) Apr. 2.
Rocklin-Colfax Second Track Construction, Southern Pacific Co.* (18) Apr. 2.
Mallet Articulated Compound Locomotive for the Boston & Albany R. R.* (18) Apr. 2.
Section 1 of the Washington Street Tunnel, Chicago.* (14) Apr. 2.
Tunnel Lining, Chicago, Milwaukee & Puget Sound Railway.* (14) Apr. 2.
Notice sur le Chemin de Fer Electrique à Crémaillère du Salève. Vagneux. (43) Jan.
Sonnette Automotrice à Plaque Tournante de l'Atchison, Topeka, and Santa Fe Railway Co. (E.-U.)* F. Hofer. (33) Feb. 26.
Note sur le Fonctionnement et le Réglage des Locomotives Compound à Quatre Cylindres.* Maurice Demoulin. (34) Mar.
Note sur le Chemin de Fer de Brickaville à Tananarive.* R. Godfernaux. (38) Mar.
Note sur un Nouveau Procédé Permettant de Mesurer les Efforts aux Diverses Articulations d'une Transmission de Mouvement.* Paul Conte. (38) Mar.
La Première Application du Système Mallet aux Locomotives à Grande Vitesse.* Henry Martin. (33) Mar. 12.

Railroads, Street.

Tramway Repair Works and Machinery.* C. Pendlebury, M. I. Mech. E. (10) Mar.
A New Subway Line for New York City; its History.* (13) Mar. 10.
Reinforcement of Conduit Rails at Washington.* Philander Betts. (17) Mar. 12.
Rail Wear on London Underground Lines.* (17) Mar. 12.
Movement of Passengers on Platforms and Stairways. J. Vipond Davies and J. Hollis Wells. (Abstract of paper read before the Am. Inst. of Archts.) (15) Mar. 18.
Revision of Oak Park Elevated at Entrance to New North Western Terminal, Chicago.* (15) Mar. 18.
Constructing the Paris Subway, a Description of the Freezing Process Employed.* Lucien Fournier. (From *La Nature.*) (19) Mar. 26.

Sanitation.

Furnace Heating in an Eight-Room School.* (101) Mar. 12.
A Large Storm Sewer Supported on Piers.* (14) Mar. 19.
Sewage Treatment to Prevent River Pollution. George A. Johnson. (Paper read before the Ind. San. and Water Supply Assoc.) (14) Mar. 19.
Heating a Shop Through Its Floors.* (64) Mar. 22.
Sewage Distribution Tests at Mount Vernon, N. Y.* Charles A. Hammond, M. Am. Soc. C. E. (13) Mar. 24.
Cleansing and Disinfecting Dwellings after the Paris Floods. (From *La Technique Sanitaire.*) (13) Mar. 24.
The Drainage of a Country House.* J. D. Watson. (Paper read before the San. Inst.) (96) Serial beginning Mar. 25.
Some German Ozone Apparatus.* (26) Mar. 25.
Heating and Ventilating the Morgan Memorial Building, Hartford.* Putnam A. Bates. (14) Mar. 26.
The Sewage Testing Station of the Sanitary District of Chicago.* Langdon Pearse, Assoc. M. Am. Soc. C. E. (13) Mar. 31.
Sewer Cleaning in Brooklyn. (14) Apr. 2.
Sanitation in Construction Camps of the Catskill Aqueduct.* (14) Apr. 2.
Construction Methods on the Louisville Sewerage Works.* Roger DeL. French. (14) Apr. 2.
The Southern Outfall Sewer, Louisville.* Wm. Mayo Venable. (14) Apr. 2.

Structural.

Monel Metal.* A. Stansfield. (5) Jan., 1909.
Foundations for Addition to Manhattan Life Building, New York City.* T. Kennard Thomson. (5) Jan., 1909.
Modern Fireproof Construction, Facts and Figures.* W. N. Moorhouse. (5) Jan., 1909.
Unusual Method of Erecting 90-Foot Stack.* Warren O. Rogers. (64) Mar. 8.

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* Illustrated.

Structural—(Continued).

Cantilever Construction and Wind-Bracing Details in the People's Gas Light & Coke Building, Chicago.* (13) Mar. 10.
Lateral Reinforcement for Concrete Compression Members. Robert A. Cummings. (Abstract of paper read before the National Assoc. of Cement Users.) (14) Mar. 12; (13) Mar. 17.
A Reinforced-Concrete Machinery Warehouse.* H. Milton Boyajohn. (14) Mar. 12.
The Empalme Shops, Southern Pacific Railroad of Mexico.* (14) Mar. 12.
Effect of Sea Water on the Tensile Strength of Mortar.* Cloyd M. Chapman. (Abstract of paper read before the National Assoc. of Cement Users.) (14) Mar. 12; (13) Mar. 10.
Inside-Glazed Greenhouses in the Berlin Botanical Gardens.* (13) Mar. 17.
Steelwork in the New York Municipal Building.* (14) Mar. 19.
The New Plant of the Carter's Ink Company.* (14) Mar. 19.
A Simple Method of Computing the Strength of Flat Reinforced Concrete Plates.* Angus B. MacMillan. (Paper read before the National Assoc. of Cement Users.) (86) Mar. 23; (13) Mar. 31.
Steelwork of the Bryant Building, New York.* (14) Mar. 26.
A New Floor Construction of Separately Molded Reinforced Concrete Hollow Beams.* Theodore Ahlborn. (86) Mar. 30.
Construction and Cost of an Inexpensive Steam Curing Oven for Concrete Block Plants with Some Notes on Operation. F. S. Phipps. (Abstract of paper read before the National Assoc. of Cement Users.) (86) Mar. 30.
A Method of Depositing Concrete by Chutes in Building Construction with Costs of Actual Work.* (86) Mar. 30.
Further Tests on the Effect of Electrolysis on Concrete.* O. L. Eltinge. (13) Mar. 31.
A Protection Against Electrolysis for Anchor Bolts.* (13) Mar. 31.
Deep Pneumatic Foundations for New York Municipal Building.* (14) Apr. 2.
Underpinning the Mt. Sinai Hospital Dispensary.* (14) Apr. 2.
Open Cofferdam Foundations in Quicksand.* (14) Apr. 2.
Improving the Seventh Regiment Armory, New York.* (14) Apr. 2.
Etude Expérimentale de la Résistance des Soudures.* Ch. Fremont. (33) Feb. 26.
Recherches sur l'Influence des Brusques Changements de Température sur l'Acier Doux.* Bruno Zschokke. (93) Mar.
Coloration des Argiles par les Couleurs d'Aniline. M. F. Grandjean. (93) Mar.

Topographical.

Phototopography, with Special Reference to the Alaskan Boundary.* P. W. Greene. (5) Jan., 1909.
Some Notes on a Method of Obtaining Time and Latitude. G. Blanchard Dodge. (5) Jan., 1909.

Water Supply.

High-Duty Pumping Engines at Milwaukee, Wis., and Nashville Tenn.* (13) Vol. 63.
On the Variation of the Coefficient of Discharge for Small Orifices.* T. P. Strickland. (5) Jan., 1909.
Sun River Project, Montana: United States Reclamation Service. S. B. Robbins. (Paper read before the Montana Soc. of Engrs.) (1) Feb.
Progress Report on Proposed Specifications for Post Hydrants. (New England Water Works Assoc.) (28) Mar.
Report of Committee Appointed to Collect Data Relating to Awards for Water and Water-Power Diversion. (New England Water Works Assoc.) (28) Mar.
The Underlying Principles Governing Riparian Water Rights and Diversion Suits. Charles F. Choate, Jr. (28) Mar.
Water Supply and Treatment for Power Plant Purposes. William Miller Booth. (Abstract of paper read before the Am. Water Works Assoc.) (60) Mar.
The Grindleford to Rowsley Section of the Derwent Aqueduct.* Alex. H. Jameson, A. M. Inst. C. E. (12) Serial beginning Mar. 4.
Plans and Specifications for Early Timber, Earth and Masonry Dams Built in Connecticut.* C. E. Chandler. (Abstract of paper read before the Conn. Soc. of Civ. Engrs.) (86) Mar. 9.
Some Data on Water Purification from Poughkeepsie, N. Y. (86) Mar. 9.
A Special Type of Head-Gate for Irrigating Canals.* (14) Mar. 12.
Necessary Elements for Water Works Valuation. John W. Alvord. (Paper read before the Ind. San. and Water Supply Assoc.) (14) Mar. 12; (13) Mar. 10.
The Construction of the Rainbow Falls Hydroelectric Development.* (14) Mar. 12.

* Illustrated.

Water Supply—(Continued).

The Groined Arch in Filter and Reservoir Construction.* Thomas H. Wiggin. (Paper read before the National Assoc. of Cement Users.) (14) Serial beginning Mar. 12.

The Nisqually Hydro-Electric Plant of the City of Tacoma, Washington.* (13) Mar. 17.

Effect of Water Diversion for Power Purposes on Niagara Falls. (Abstract of Report to the Chf. of Engrs.) (13) Mar. 17.

Proposed Hydroelectric Development on the Teton River, Idaho.* (27) Mar. 17.

Partial Failure of a Concrete Dam at Austin, Pa.* (13) Mar. 17.

Completion of Liverpool Waterworks at Vyrnwy.* (12) Serial beginning Mar. 18.

Action of St. Louis Water on Metals and Alloys. (14) Mar. 19.

Building the Olive Bridge Dam for the Catskill Water Supply.* (46) Mar. 19.

Electric Power Development on the Los Angeles Water-Supply Aqueduct.* (13) Mar. 24.

Lowering of Ground-Water Level by City Water-Supplies of Indiana. Charles Brossman. (Abstract of paper read before the Ind. San. and Water Supply Assoc.) (13) Mar. 24; (86) Mar. 9.

Reinforced Concrete on Irrigation System. B. A. Etcheverry. (From *Jour. of Tech., Cal.*) (96) Mar. 25.

The Bear River Plant of the Telluride Power Company.* (14) Mar. 26.

Bearing of Court Decisions on Water-Works Management. Leonard Metcalf. (Abstract of paper read before the Penn. Water-Works Assoc.) (14) Mar. 26.

Some Methods and Cost of Building Reinforced Concrete Cisterns.* Benjamin Brooks. (86) Mar. 30.

Hydroelectric Plant, with Storage, Forty-six Thousand Volt System of the La Crosse Water-Power Co., of La Crosse, Wisconsin.* R. A. Lundquist. (27) Mar. 31.

Heavy Regrading by Means of Hydraulic Sluicing at Seattle, Wash.* Geo. Holmes Moore. (13) Mar. 31.

A Break in a Water Main at Springfield, Mass. Elbert E. Lochridge, Assoc. M. Am. Soc. C. E. (13) Mar. 31.

The Laramie Tunnel.* R. L. Herrick. (45) Apr.

The Artesian Wells of the Water Supply of Memphis, Tenn. (60) Apr.

A General Review of Hydroelectric-Engineering Practice.* Frank Koester. (9) Apr.

Parallel Operation of Hydroelectric Plants. W. S. Lee. (42) Apr.

Hydroelectric Power as Applied to Irrigation.* John Coffee Hays. (42) Apr.

Construction of the Belle Fourche Dam.* O. T. Ready, Assoc. M. Am. Soc. C. E. (14) Apr. 2.

The Wallkill Pressure Tunnel of the Catskill Aqueduct.* (14) Apr. 2.

The Hunters Brook Tunnel Construction. (14) Apr. 2.

A Hydroelectric Development on the Weber River, Utah.* (14) Apr. 2.

Development of the Ninety-Nine Island Station of the Southern Power Company.* Curtis A. Mees, M. Am. Soc. C. E. (14) Apr. 2.

A Portable Floating Cofferdam.* (14) Apr. 2.

Submerged Pipe Line from Jersey City to Ellis Island. (14) Apr. 2.

The Salmon River Dam and Irrigation Project, Idaho.* (14) Apr. 2.

Notice sur l'Usine de la Coulouvrenière et le Service des Eaux de la Ville de Genève et des Environs. Vagneux. (43) Jan.

Waterways.

Reclamation and Development of the New Jersey Coast.* Geo. L. Watson. (5) Jan., 1909.

The Construction of a Concrete Mass and Blockwork Quay Wall by Helmet Divers in Open Water.* John Taylor. (5) Jan., 1909.

The Shut-Off Dam at the Charles River Basin.* James W. Rollins, Jr. (Paper read before the Boston Soc. of Civ. Engrs.) (1) Jan.

Distribution of Sea Water in the Charles River Basin after Excluding Tidal Waters.* Morton F. Sanborn. (13) Mar. 10.

Stress-Lines and Steam-Lines.* (11) Mar. 11.

Driving Piles Without a Pile Driver.* George H. Lodge. (46) Mar. 12.

The Efficiency and Cost of Concrete for the Preservation of Piles Exposed to Sea Water. Healy-Tibbets Construction Co. (Paper read before the National Assoc. of Cement Users.) (86) Mar. 16.

Collapse of an Important Canal Head Sluice in Egypt.* *Sir* Hanbury Brown. (12) Mar. 18.

Structural Features of New Concrete Recreation Pier at Albany, N. Y.* (86) Mar. 23.

Some Records of Work with a Scraper Bucket Excavator on the New York Barge Canal.* (86) Mar. 23.

The Engineering Features of the Recent Floods in Paris.* (13) Mar. 24.

*Illustrated.

Waterways (Continued).

The Movable Dam Across the Red River at St. Andrew's Rapids.* H. P. Borden, A. M. Can. Soc. C. E. (**14**) Mar. 26.
Cement and Concrete for Protecting Piles in Sea Water. Ralph Barker. (Paper read before the National Assoc. of Cement Users.) (**14**) Mar. 26.
Representative Concrete Structures on the New York Barge Canal and Methods of Inspecting, Mixing and Handling Concrete.* Russel S. Greenman. (Abstract of paper read before the National Assoc. of Cement Users.) (**86**) Mar. 30.
The Cost of Terminal Freight Handling in the Port of New York.* (**13**) Mar. 31.
Construction of the Tribes Hill Lock and Dam, Barge Canal.* (**14**) Apr. 2.
The Construction Plant on Contract 40, Barge Canal.* (**14**) Apr. 2.
Excavation Methods on Contract 9, Barge Canal.* (**14**) Apr. 2.
Hydraulic Excavation in the Pacific Division of the Panama Canal.* (**14**) Apr. 2.
Lock of the Black Rock Harbor Improvement, Buffalo.* (**14**) Apr. 2.
Progress in the Improvement of the Detroit River.* (**14**) Apr. 2.
A Concrete Dock on the Chicago River.* (**14**) Apr. 2.
The New King's Dock at Swansea.* C. Van Langendonck. (**19**) Apr. 2.
Building the Huge Concrete Locks at Gatun, Panama.* (**46**) Apr. 2.

* Illustrated.

Vol. XXXVI. APRIL, 1910. No. 4.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

CONTENTS

PLATES

Vol. XXXVI. APRIL, 1910. No. 4.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.
MEADOWS DIVISION AND HARRISON TRANSFER YARD.

By E. B. Temple, M. Am. Soc. C. E.

To be Presented June 1st, 1910.

The New York Tunnel Extension of the Pennsylvania Railroad diverges from the New York Division in the Town of Harrison, N. J., and, ascending on a 0.5% grade, crosses over the tracks of the New York Division and the main line of the Delaware, Lackawanna and Western Railroad. Thence it continues, with light undulating grades, across the Hackensack Meadows to a point just east of the Northern Railroad of New Jersey and the New York, Susquehanna and Western Railroad, where it descends to the tunnels under Bergen Hill and the North River. (Plate LXXI.)

That portion of the line lying west of the portals of the Bergen Hill Tunnels has been divided into two sections: First, the most westerly, known as the Harrison Transfer Station and Yard, which is located on the southern side of the New York Division, Pennsylvania Railroad, and extends from the connection with the New York Division

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.


ARLINGTON
KEARNEY
NEWARK
HARRISON
Harrison Yard
INTERCHANGE STATION
PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD
RECONSTRUCTED GREENWOOD LAKE BR. (ERIE R.R.)
PATERSON & NEWARK BR. (ERIE R.R.)
NEWARK & JERSEY CITY TURNPIKE
DELAWARE LACKAWANNA & WEST. R.R.
PENNSYLVANIA R.R.
Secaucus Sta.
Snake Hill
Drawbridge
Tyler Park
Sawmill
Marion
Portal
UNION
WEEHAWKEN
HOBOKEN
JERSEY CITY
HUDSON RIVER
MANHATTAN
HACKENSACK RIVER
PASSAIC
BAYONNE PIPE LINE
PLANK ROAD
C. R.R. OF N. J.
COUNTY ROAD
BOONTON BR. D.L. & W. R.R.
ERIE R.R.
N.Y. SUSQUEHANNA & WESTERN R.R.
NORTHERN R.R. OF NEW JERSEY
U.N.J. R.R. & C.C's. R.R.
PENNSLVANIA TUNNEL AND TERMINAL R. R.
NEW YORK DIVISION
MEADOWS DIVISION
NORTH RIVER DIVISION
HARRISON YARD
Top of Rail
Weehawken Shaft
BERGEN HILL TUNNEL
Note. Elev. 2.19 Meadows Div. equals Elev. 300.0 North River Division
Hackensack River
North River
Secaucus Road
Hudson County Boulevard
Hackensack Plank Road
Paterson Plank Road
Bergen Hill Tunnel Portal
Weehawken Tunnels
Weehawken Shield Chamber
PROFILE ON CENTER LINE

tracks at grade up to the point of crossing the same, where the Pennsylvania Tunnel and Terminal Railroad has its beginning; second, the Meadows Division of the Pennsylvania Tunnel and Terminal Railroad, which is a double-track railroad, 5.08 miles long, extending from a point just west of the bridge over the New York Division to a point 300 ft. west of the western portals of the Bergen Hill Tunnels. (Plate LXXII.)

Harrison Transfer Station and Yard.—The necessities for the Harrison improvements are two-fold: First, as a place to change motive power from steam to electric, and *vice versa;* second, as a transfer for passengers from trains destined to the new Station at Seventh Avenue and 33d Street, New York City, to steam or rapid transit trains destined to the present Jersey City Station, or to the lower part of New York City *via* the Hudson and Manhattan Tunnels, and *vice versa.*

All steam trains from Philadelphia, the South, and the West, from New Jersey seashore resorts, and local trains on the New York Division bound for the new Pennsylvania Station, will change their motive power from steam to electric engines at the Harrison Transfer Station. Likewise, all trains from the Tunnel Line will change from electric to steam motive power there, and passengers coming from Jersey City and the southern section of New York City can take through trains at the Harrison Transfer platforms. It is estimated that the time required to make this change of motive power, or to transfer passengers, will not exceed 3½ min.

The plan at Harrison provides at present for two platforms, each 1 100 ft. long and 28 ft. wide, and having ample shelters and waiting rooms, connected by a 12-ft. tunnel under the tracks, provision being made for two additional platforms when necessity requires their construction. The platforms are supported on walls of reinforced concrete, with an overhang to provide a refuge for employees from passing trains. The concrete walls are supported on wooden piles, prevented from spreading by ⅞-in. tie-rods at 10-ft. intervals, and embedded in concrete under the paving of the platform. As the elevation of the top of the platform is +21.83, and the top of the piles is +14.54 above mean tide, the piles will, of course, decay; but, as the embankment has been completed for some time and is well packed and settled, the concrete being deposited directly on the embankment, very little trouble from settlement is anticipated when the piles decay. The surface of

the platforms, with the exception of the edges, is to be of brick, on a concrete base; and, if settlement occurs, the bricks can be taken up and re-surfaced. The tops of the platforms are 3 ft. 10 in. above the top of the rail and on a level with the floors of the cars, so that passengers may enter or leave trains without using steps, as all cars which will enter the Pennsylvania Station, New York City, are to be provided with vestibules having trap-doors in the floor to give access to either high or low platforms. Details of the platforms are shown on Plates LXXIII and LXXIV.

As planned at present, there will be four main running tracks, one adjacent to each side of the two platforms, providing standing room for four of the longest trains, two in each direction, or double the number of trains of ordinary length, so that passengers having to tranfer from a train destined to the Pennsylvania Station at 33d Street to a train destined for the Jersey City Station or the Hudson and Manhattan Tunnels will merely cross the platform. Between the two interior main tracks are two shifting tracks, so that between the platforms there will be two passenger tracks on which trains will stop to change motive power and transfer passengers, and two shifting tracks for rapid despatching of the empty engines and motors, each of the four tracks being 15 ft. from center to center to allow for uncoupling and inspection of cars.

An efficient system of connections and cross-overs is provided for all tracks, and there is ample storage capacity for 10 steam engines at the western end of the platforms and 20 electric motors at the eastern end, both of which are conveniently located for quick movement, with provision for additional storage tracks, if required. Steam engines, upon being disconnected, can be quickly sent to the main engine storage yard, and by the use of a loop track no turntable is required. The main engine storage yard is located south of the running tracks adjoining the bulkhead along the Passaic River, where provision is made for the storage of 20 engines. There are two 50 000-gal. water tanks, an ash-pit, inspection-pit, work-pit, sand-hopper, and the necessary buildings. Water is brought from the city water main in the Meadows Yard, on the New York Division, about 8 200 ft. eastward from the center of this yard.

It was at first planned to locate a power-house and car and engine repair shops in the yard, but as the ultimate extent of the electrifica-

PLATE LXXII
PAPERS, AM. SOC. C. E.
APRIL, 1910.
TEMPLE ON
MEADOWS DIV AND HARRISON YARD
PENN. R. R. TUNNELS.

tion of the New York Division cannot now be determined, the facilities in the large power-house in Long Island City, and in the shop and round-house in the Meadows Yard of the New York Division, were increased to provide for the power and repairs necessary for the next few years. In order to reach the Meadows shops and round-house without interfering with the present passenger and freight tracks, it was necessary to build track connections with the Meadows Yard. Twelve stalls of the existing round-house were extended to accommodate the motive power; a large transfer table and pit were increased in size, and an additional ash-pit and engine storage tracks were constructed.

Any extensive repairs to the electric engines will be made for the present in the Jamaica Shops, Long Island; and the large shops at Trenton, on the New York Division, as well as the Meadows Shops, will be available for repairs to the steam locomotives. There is ample room at Harrison, and plans have been prepared providing for storage and light repair of cars, locomotives, electric motors, and rapid transit trains, if the future demands require such construction at this place.

The rapid transit line will extend from Park Place, Newark, to Harrison, and thence over the present line of the Pennsylvania Railroad, which will be electrified, to a junction with the Hudson and Manhattan Railroad Company's tunnel tracks at Prior Street, Jersey City. It will be constructed and owned by the Pennsylvania Railroad Company. A joint and frequent through service will be conducted by both companies between Park Place, Newark, and the terminal of the Hudson and Manhattan Railroad, in New York City, by the use of multiple-unit trains similar to those now being operated in the Hudson and Manhattan tunnels. These trains will pick up and discharge Pennsylvania Railroad passengers at the Harrison Transfer Station, so that all passengers bound for lower New York City, who desire to use the tunnel service, will make the change at Harrison instead of at Jersey City as at present. Provision is made for two additional platforms, each 1 100 ft. long, to accommodate the rapid transit trains when the present platforms prove inadequate. The existing passenger tracks between the Harrison Transfer Yard and Summit Avenue, Jersey City, where a new local passenger station will be constructed, will be used jointly by steam and electric trains.

The embankment for the Harrison Yard was made, under contract dated July 21st, 1906, with Henry Steers, Incorporated, of New York

City, of cellar earth from New York City, and with rock and earth excavated from the Pennsylvania Station and cross-town tunnels. It was necessary to construct 1 000 ft. of stone and crib bulkhead along the bank of the Passaic River. The plan of the yard was prepared by a committee of operating, electrical, and engineering officers, consisting of Mr. F. L. Sheppard, General Superintendent, New Jersey Division, Pennsylvania Railroad Company; George Gibbs, M. Am. Soc. C. E., Chief Engineer, Electric Traction and Terminal Station Construction, Pennsylvania Tunnel and Terminal Railroad Company; Mr. J. A. McCrea, General Superintendent, Long Island Railroad Company; Mr. C. S. Krick, Superintendent, Pennsylvania Tunnel and Terminal Railroad Company; Mr. A. M. Parker, then Principal Assistant Engineer, New Jersey Division, Pennsylvania Railroad Company, now Superintendent, Hudson Division; and approved by Mr. A. C. Shand, Chief Engineer, Pennsylvania Railroad Company, and Chief Engineer, Meadows Division, Pennsylvania Tunnel and Terminal Railroad Company.

Meadows Division, Pennsylvania Tunnel and Terminal Railroad.—The two main tracks ascending through the Harrison Yard continue on an embankment to a point 500 ft. west of the west abutment of the bridge over the New York Division tracks, which is the point of beginning of the Pennsylvania Tunnel and Terminal Railroad. From this point the line extends in a general northeasterly direction, crossing the Hackensack River, skirting the base of Snake Hill, and thence to the approach cut to Bergen Hill Tunnels. The embankment varies in height from 25 to 30 ft. above the surface of the meadows.

In this Division the following bridges were necessary:

Pennsylvania Railroad, New York Division, Passenger and Newark Freight Tracks;

Delaware, Lackawanna and Western Railroad, Morris and Essex Division;

Newark and Jersey City Turnpike;

Public Service Corporation Right of Way;

Erie Railroad, Newark and Paterson Branch;

Belleville Road, and Jersey City Water Company's Pipe Line;

Greenwood Lake Railroad (Erie Railroad), Arlington Branch;

Hackensack River;

Greenwood Lake Railroad (Erie Railroad), Reconstructed Line;

PLATE LXXIII.
PAPERS, AM. SOC. C. E.
APRIL, 1910.
TEMPLE ON
MEADOWS DIV. AND HARRISON YARD:
PENN. R. R. TUNNELS.

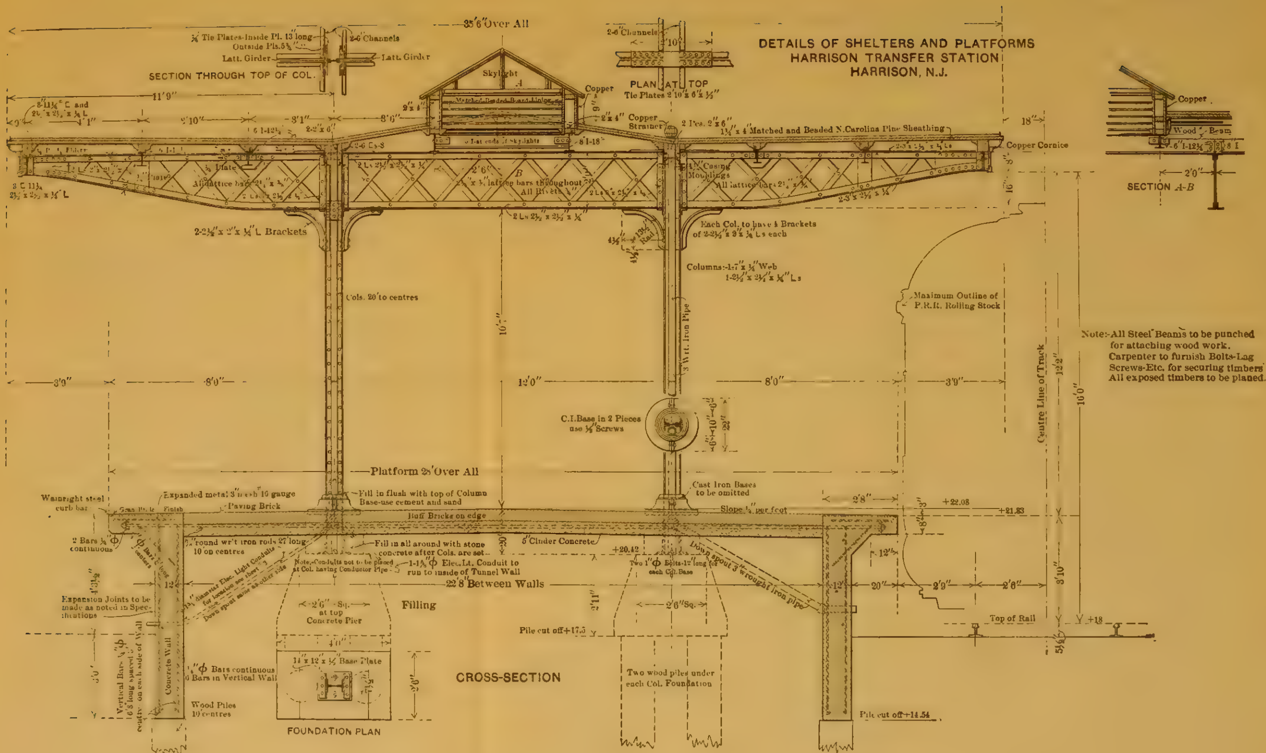
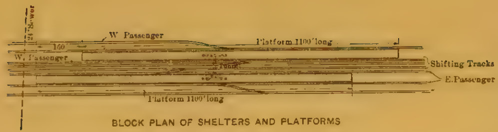


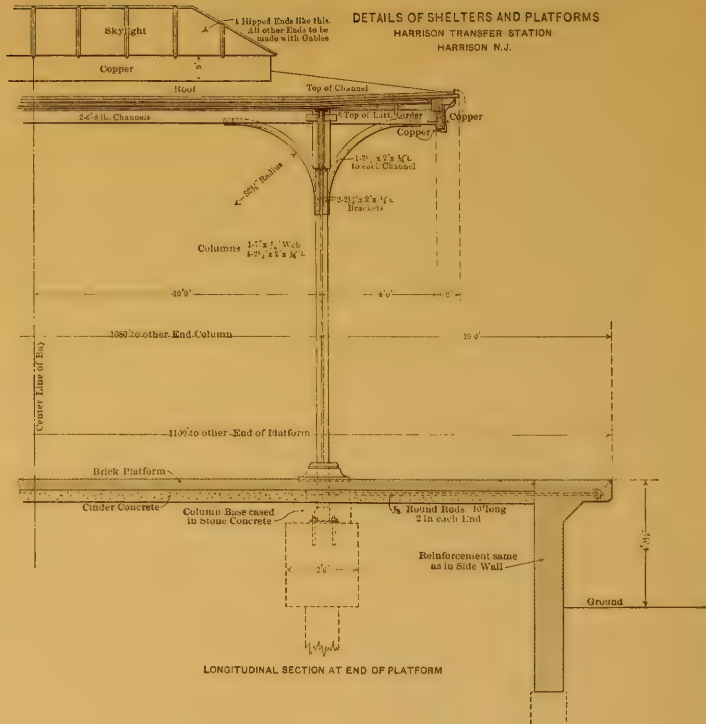
PLATE LXXIV.
PAPERS, AM. SOC. C. E.
APRIL, 1910.
TEMPLE ON
MEADOWS DIV. AND HARRISON YARD:
PENN. R. R. TUNNELS.

DETAILS OF SHELTERS AND PLATFORMS
HARRISON TRANSFER STATION
HARRISON N.J.



BLOCK PLAN OF SHELTERS AND PLATFORMS

PLAN OF STEEL IN END BAY-INTERMEDIATE BAYS SIMILAR



LONGITUDINAL SECTION AT END OF PLATFORM

Delaware, Lackawanna and Western Railroad, Boonton Branch;
Erie Railroad, Passenger Tracks;
Bridge of 11 spans over proposed yard tracks, Erie Railroad;
County Road;
Secaucus Road;
New York, Susquehanna and Western Railroad;
Northern Railroad of New Jersey.

The alignment for this distance consists of 3.57 miles of tangent and three curves, two of which are 0° 30′ each, one of the latter being at the western end of the Division, and the other adjoining Snake Hill; the third is a regular curve of 1° 54′ on the east-bound track, and a compound curve with a maximum of 2° on the west-bound track, the variation being due to the track spacing of 37 ft. from center to center in the Bergen Hill Tunnels, while on the Meadows Division it is 13 ft. from center to center.

The profile was adopted to give 18 ft. of clearance from the under side of the bridges to the top of the rail of the Erie Railroad branches, 21 ft. to the top of the rail of its main line, 19 ft. to the top of the rail of the Delaware, Lackawanna and Western Railroad, and a clearance of 24 ft. above high water in the Hackensack River. With the exception of that portion of the line adjoining the Bergen Hill Tunnels, where it was necessary to continue the 1.3% grade up to the bridge over the Northern Railroad of New Jersey, and the east-bound ascending grade of 0.5% from the Harrison platforms to the bridge over the New York Division tracks, the grades do not exceed 0.3 per cent.

When the construction of the embankment was commenced, it was expected that there would be considerable trouble by settlement due to the displacement of the soft material underlying the surface of the meadows to a depth of from 10 to 15 ft.; but, with the exception of the trouble the contractors had in maintaining their temporary trestles, the embankment as completed has settled very little. The section east of the Hackensack River was made, in great part, of rock excavated from a borrow-pit in the Town of Secaucus, north of the eastern end of the Division. The embankment was built under two contracts, one for the work east of the crossing of the Boonton Branch of the Delaware, Lackawanna and Western Railroad, under contract dated January 15th, 1907, with H. S. Kerbaugh, Incorporated, the material

being taken from the borrow-pit in narrow-gauge cars and dumped from a strong pile trestle along the total length of the section, the same being completed in 19 months; the other for the embankment west of the Boonton Branch, Delaware, Lackawanna and Western Railroad, under contract dated April 10th, 1906, with Henry Steers, Incorporated, of New York City, the material, consisting partly of cellar earth, and partly of rock and earth excavated from other sections of the Pennsylvania Tunnel and Terminal Railroad, being brought on scows up the Hackensack and Passaic Rivers from New York City. The material was handled expeditiously from the scows by orange-peel buckets operated from the shore, deposited in standard-gauge dump-cars, and transported by locomotives at one time used on the elevated railroads in New York City. No excavation whatever was required on the Meadows Division or in the Harrison Yard.

The substructures for all the bridges, except the Hackensack River Draw-bridge, are of concrete, without reinforcement, heavy enough to withstand the ordinary earth pressure for the exposed height. With the exception of three bridges, foundations were built on clay and sand; these three, on account of excessive depth of soft material, were built on piles. In some cases loose stone was deposited back of the foundations for a width of 10 or 12 ft. after the mud had been removed. This precaution has prevented trouble due to the thrust of the high embankments on the saturated material. Masonry for all these bridges was constructed under contract dated August 21st, 1905, with McMullen and McDermott, of New York City. The superstructure consisted principally of half-through girders, floor of I-beams, filled solid with concrete, on top of which were placed five layers of Hydrex felt, and water-proofing compound, protected by a layer of sand and grouted brick from the stone ballast.

The bridges over the New York Division passenger and Newark freight tracks of the Pennsylvania Railroad, and the main-line tracks of the Delaware, Lackawanna and Western Railroad, at the west end of the Meadows Division, are separated by 300 ft. of embankment. The skew angle is 9°, the total length of each bridge being about 450 ft. The floors consist of I-beams embedded in concrete.

The Hackensack River Draw-bridge consists of six spans of deck plate girders, each 110 ft. long, and a draw-span 300 ft. long, operated by two 70-h.p. electric motors. The masonry was constructed under

FIG. 1.—LIFT RAIL AND LOCKING DEVICE. DRAW PARTLY OPEN.

FIG. 2.—LIFT RAIL AND LOCKING DEVICE, DRAW CLOSED.

contract dated August 25th, 1905, with the Drake and Stratton Company, of Philadelphia; and the steelwork was furnished and erected by the Pennsylvania Steel Company, of Steelton, Pa. An important and interesting feature of the draw-bridge is the lift rail, and new rail-locking device. Mitered rails are used, with sufficient opening between the ends to prevent binding at times of expansion. It was deemed advisable that the mitered joint should occur on the abutment, or fixed span, instead of at the opening at the end of the draw. The lift rail, therefore, was a necessity; and the design, as shown on Plate LXXV, was perfected. It consists of lift-rails, 8 ft. 4 in. long, moving vertically 8 in. at the free end, reinforced on both sides by sliding steel castings, which are lifted with the rail; when the latter is dropped in place, the wedges on the castings engage at the abutment and heel joints and at one intermediate point in dove-tailed wedge seats, insuring tight contact with the rail, and absolute fastening to the deck of the bridge. The objection to the ordinary lift-rail, which in lowering must make its own joint by seating in tight boxes, has been that any slight deviation from a true line would prevent the rail from seating itself properly. This objection has been entirely overcome in this design, by allowing liberal clearance on all seats, and securing rigidity by the sliding bars and wedges which are connected with the interlocking system, so that it is impossible for a clear signal to be given unless the lift-rails and wedges are in their proper positions. This device has been operated successfully on the New York and Long Branch Railroad bridge over Raritan Bay for the last 18 months.

Each of the two main tracks on the Meadows Division, and all the main tracks in the Harrison Transfer Yard, are of standard construction, with Pennsylvania Section, 1909, 100-lb., open-hearth steel rails, and stone ballast. Every fifth tie is made 9 ft. 5 in. long, to carry the third rail for the electric current, and all joints of the running rails are bonded for the same purpose. Track-laying on the Meadows, and in Harrison Transfer Yard, has been done under contract dated April 26th, 1909, with Henry Steers, Incorporated, of New York City.

Samuel Rea, M. Am. Soc. C. E., Second Vice-President, Pennsylvania Railroad Company, is the executive officer under whose direction the work has been carried on. Mr. William H. Brown, Chief Engineer, Pennsylvania Railroad Company, and Chief Engineer of the Meadows

Division, also a Member of the Board of Consulting Engineers for the tunnel extension, until his retirement by age limit on February 28th, 1906, located and started the construction of the line from Harrison to the western portals of the Bergen Hill Tunnels, which latter point was the westernmost limit of authority of the Board of Consulting Engineers. Mr. A. C. Shand succeeded Mr. Brown as Chief Engineer of the Pennsylvania Railroad Company, and as Chief Engineer of the Meadows Division, with the writer, who was Assistant Chief Engineer of the Pennsylvania Railroad Company, and had been closely associated with Mr. Brown at the time of the location of the line and its earlier period of construction. H. R. Leonard, M. Am. Soc. C. E., Engineer of Bridges and Buildings, Pennsylvania Railroad Company, designed the Hackensack River Bridge, the superstructures of the other bridges, and the rail-locking device on the Hackensack River Draw-bridge. The surveys and construction of the Meadows Divison and of the Harrison Transfer Yard have been in charge of Mr. William C. Bowles, Engineer of Construction.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

LOCOMOTIVE PERFORMANCE ON GRADES OF VARIOUS LENGTHS.*

By Beverley S. Randolph, M. Am. Soc. C. E.

In the location of new railways and the improvement of lines already in operation, it is now well recognized that large economies can be effected by the careful study of train resistance due to grades and alignment, distributing this resistance so as to secure a minimum cost of operation with the means available for construction.

While engaged in such studies some years ago the attention of the writer was attracted by the fact that the usual method of calculating the traction of a locomotive—by assuming from 20 to 25% of the weight on the drivers—was subject to no small modification in practice.

In order to obtain a working basis, for use in relation to this feature, he undertook the collection of data from the practical operation of various roads. Subsequent engagements in an entirely different direction caused this to be laid aside until the present time. The results are given in Table 1, from which it will be seen that the percentage of driver weight utilized in draft is a function of the length as well as the rate of grade encountered in the practical operation of railways.

In this table, performance will be found expressed as the percentage of the weight on the drivers which is utilized in draft. This is calculated on a basis of 6 lb. per ton of train resistance, for dates

* This paper will not be presented at any meeting, but written communications on the subject are invited for publication with it in *Transactions*.

prior to 1880, this being the amount given by the late A. M. Wellington, M. Am. Soc. C. E.,* and 4.7 lb. per ton for those of 1908-10, as obtained by A. C. Dennis, M. Am. Soc. C. E.,† assuming this difference to represent the advance in practice from 1880 to the present time. Most of the data have been obtained from the "Catalogue of the Baldwin Locomotive Works" for 1881, to which have been added some later figures from "Record No. 65" of the same establishment, and also some obtained by the writer directly from the roads concerned. Being taken thus at random, the results may be accepted as fairly representative of American practice.

Attention should be directed to the fact that the performance of the 10-34 E, Consolidation locomotive on the Lehigh Valley Railroad in 1871 is practically equal to that of the latest Mallet compounds on the Great Northern Railway. In other words, in the ratio between the ability to produce steam and the weight on the drivers there has been no change in the last forty years. This would indicate that the figures are not likely to be changed much as long as steam-driven locomotives are in use. What will obtain with the introduction of electric traction is "another story."

These results have also been platted and are presented in Fig. 1, with the lengths of grade as abscissas and the percentages of weight utilized as ordinates. The curve sketched to represent a general average will show the conditions at a glance. The results may at first sight seem irregular, but the agreement is really remarkable when the variety of sources is considered; that in many cases the "reputed" rate of grade is doubtless given without actual measurement; that the results also include momentum, the ability to utilize which depends on the conditions of grade, alignment, and operating practice which obtain about the foot of each grade; and that the same amount of energy due to momentum will carry a train further on a light grade than on a heavy one.

There are four items in Table 1 which vary materially from the general consensus. For Item 9, the authorities of the road particularly state that their loads are light, because, owing to the congested condition of their business, their trains must make fast time. Item 10 represents very old practice, certainly prior to 1882, and is "second-

* "The Economic Theory of Railway Location," 1887 edition, p 502.

† *Transactions*, Am. Soc. C. E., Vol. L, p. 1.

hand." The load consisted of empty coal cars, and the line was very tortuous, so that it is quite probable that the resistance assumed in the calculation is far below the actual. Items 15 and 17 are both high. To account for this, it is to be noted that this road has been recently completed, regardless of cost in the matter of both track and rolling stock, and doubtless represents the highest development of railroad practice. Its rolling stock is all new, and is probably in better condition to offer low resistance than it will ever be again, and

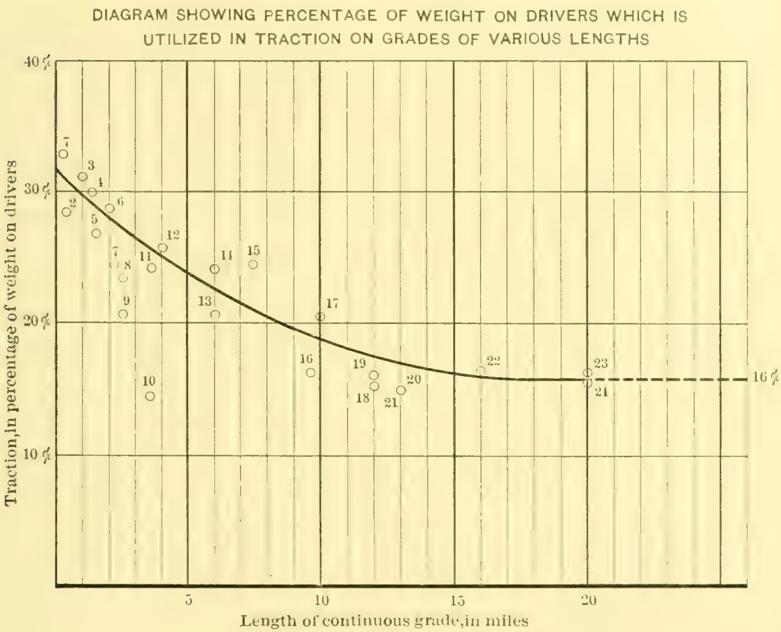


Fig. 1.

there were no "foreign" cars in the trains considered. The train resistance, therefore, may be naturally assumed to be much less than that of roads hauling all classes of cars, many of which are barely good enough to pass inspection. As the grades are light in both cases, this feature of train resistance is larger than in items including heavier grades. Attention should be called to the fact that a line connecting the two points representing these items on Fig. 1 would make only a small angle with the sketched curve, and would be practically parallel to a similar line connecting the points represented

by Items 13 and 16. There is, therefore, an agreement of ratios, which is all that needs consideration in this discussion.

Wellington, in his monumental work on railway location, presents a table of this character. The percentages of weight on the drivers which is utilized in draft show the greatest irregularity. He does not give the length of the grades considered, so that it is impossible to say how far the introduction of this feature would have contributed to bring order out of the chaos. In his discussion of the table he admits the unsatisfactory character of the results, and finally decides on 25% as a rough average, "very approximately the safe operating load in regular service." He further states that a number of results, which he omits for want of space, exceeds 33 per cent. The highest shown in Table 1 will be found in Item 1 (0.06 mile, 0.066 grade), showing 33 per cent. There is no momentum effect here, as the grade is a short incline extending down to the river, and the start is necessarily a "dead" one. The reports of Item 3, which shows 31%, and Item 5, which shows 27%, state specifically that the locomotives will stop and start the loads given at any point on the grade.

The results of a series of experiments reported by Mr. A. C. Dennis in his paper, "Virtual Grades for Freight Trains," previously referred to, indicate a utilization of somewhat more than 23%, decreasing with the speed.

All this indicates that the general failure of locomotives to utilize more than from 16 to 18% on long grades, as shown by Table 1, can only be due to the failure of the boilers to supply the necessary steam. While the higher percentage shown for the shorter grades may be ascribed largely to momentum present when the foot of the grade is reached, the energy due to stored heat is responsible for a large portion of it.

When a locomotive has been standing still, or running with the steam consumption materially below the production, the pressure accumulates until it reaches the point at which the safety valve is "set." This means that the entire machine is heated to a temperature sufficient to maintain this pressure in the boiler. When the steam consumption begins to exceed the production, this temperature is reduced to a point where the consumption and production balance.

The heat represented by this difference in temperature has passed into the steam used, thus adding to the energy supplied by the com-

bustion going on in the furnace. The engines, therefore, are able to do considerably more work during the time the pressure is falling than they can do after the fall has ceased.

The curve in Fig. 1 would indicate that the energy derived from the two sources just discussed is practically dissipated at 15 miles, though the position of the points representing Items 16, 18, 19, 20, and 21 would indicate that this takes place more frequently between 10 and 12 miles. From this point onward the performance depends on the efficiency of the steam production, which does not appear to be able to utilize more than 16% of the weight on the drivers. The diagrams presented by Mr. Dennis in his paper on virtual grades, and by John A. Fulton, M. Am. Soc. C. E., in his discussion of that paper, indicate that similar results would be shown were they extended to include the distance named.

From this it would appear that a locomotive is capable of hauling a larger train on grades less than 10 miles in length than on longer grades, and that, even when unexpectedly stopped, it is capable of starting again as soon as the steam pressure is sufficiently built up. Conversely, it should be practicable to use a higher rate of ascent on shorter grades on any given line without decreasing the load which can be hauled over it. In other words, what is known as the "ruling grade" is a function, strictly speaking, of the length as well as the rate of grade.

In any discussions of the practicability of using a higher rate on the short grades, which the writer has seen, the most valid objection has appeared to be the danger of stalling and consequent delay. As far as momentum is relied on, this objection is valid. Within the limits of the load which can be handled by the steam, it has small value, as it is only a question of waiting a few minutes until the pressure can be built up to the point at which the load can be handled. As this need only be an occasional occurrence, it is not to be balanced against any material saving in cost of construction.

The writer does not know of any experiments which will throw much light on the value of heat storage as separated from momentum, though the following discussion may prove suggestive:

A train moving at a rate of 60 ft. per sec., and reaching the foot of a grade, will have acquired a "velocity head" of 56.7 ft., equivalent to stored energy of $56.7 \times 2\,000 = 113\,400$ ft-lb. per ton. On a 0.002

TA-

Item No.	Length of grade, in miles.	Rate of grade.	Maximum curvature.	Compensation.	Gross weight of load, in tons.	Weight of tender, in tons.	Weight of locomotive, in tons.	Weight on drivers, in tons.	Percentage of weight on drivers utilized in draft.	Class.	Maker.	Railroad.
1	0.06	0.066	......	...	115	..	37.5	29	0.330	8–28⅓ C	Baldwin.	Morgan's Louisiana & Texas..........
2	0.33	0.0203	25° 20'	....	242	25	35	23	0.285	8–28 C	"	Long Island.........
3	1.0	0.06	16°	0.05	192	22	57.5	50	0.310	10–36 E	"	Atchison, Topeka & Santa Fe..........
4	1.3	0.0127	......	....	600	16	40	32.5	0.300	Mogul.	"	Chillan & Talcahuana................
5	1.4	0.0128	3°12'	....	750	15	51	44	0.270	10–34 E	"	Chicago, Burlington & Quincy.........
6	2.0	0.01	......	....	1 000	15	51	44	0.291	10–34 E	"	Chicago, Burlington & Quincy ....
7	2.2	0.013	3°	....	725	15	51	44	0.245	10–34 E	"	Chicago, Burlington & Quincy ....
8	2.5	0.0144	6°	....	400	27	42	32	0.237	10–32 E	"	St. Louis & San Francisco ....
9	2.5	0.004	......	....	2 700	70	96.7	85.8	0.207	H 6 - A	Pa. R.R.	Cumberland Valley.
10	3.5	0.033	14°	....	100	25	35	35	0.160	....	....	....
11	3.6	0.035	10°	0.05	236	22	57.5	50	0.245	10–36 E	Baldwin.	Atchison, Topeka & Santa Fe..........
12	4 0	0.0085	4°	....	1 020	30	51	44	0.256	10–34 E	"	Missouri Pacific.....
13	6 0	0.0145	......	....	308	25	38	28	0.207	10–28 D	"	Western Maryland.
14	6.0	0.020	10°	0.05	460	32	57.5	50	0.242	10–34 E	"	Atchison, Topeka & Santa Fe..........
15	7.5	0.002	......	C	6 152	86	134 5	109.5	0.243	Mallet.	"	Virginian Ry........
16	9.75	0.018	......	....	200	18	29	29	0.170	....	....	Pennsylvania ....
17	10 0	0.006	......	C	6 173	86	299	265	0.203	Mallet.	Baldwin.	Virginian Ry........
18	12 0	0.018	10°	....	280	30	51	44	0 160	10–34 E	"	Lehigh Valley, Wyoming Div.........
19	12.0	0.022	......	....	850	74	175	156	0.166	D-D 16	"	Great Northern.....
20	13.0	0.022	......	....	800	74	177	158	0.153	D-D 1	"	Great Northern.....
21	13.0	0.022	14°	....	415	50	91	83	0 154	Consol.	"	Baltimore & Ohio...
22	16.0	0.0044	......	....	9 500	30	51	44	0.164	10–34 E	"	Central of N. J......
23	20.0	0.022	......	....	500	62	97.5	90	0.170	F-8, Consol.	"	Great Northern.....
24	20.0	0.022	......	....	800	74	177	158	0.159	L-1, Mallet.	"	Great Northern.....

BLE 1.

Reporting Officer.	Year.	Source of Data.	Remarks.
Newell Tilton, Asst. Supt.	1880	Baldwin Catalogue, 1881, p. 134	
S. Spencer, Gen. Supt.	1878	" " 1881, " 72	10 miles per hour.
J. D. Burr, Asst. Engr.	1879	" " 1881, " 115	8 " " " Stops and starts on grade.
J. E. Martin, Local Supt.	1879	" " 1881, " 100	
H. B. Stone	1880	" " 1881, " 116	Stops and starts at any point on grade.
"	1880	" " 1881, " 116	
"	1880	" " 1881, " 116	
C. W. Rogers, Gen. Mgr.	1879	" " 1881, " 87	
....	1910	....	
....	....	Trautwine's Pocket Book, Ed. 1882, p. 412....................	Empty cars; many curves and reversions.
J. D Burr, Asst. Engr.	1879	Baldwin Catalogue, 1881, p. 114	
John Hewitt, Supt. M. P.	1880	" " 1881, " 112	
D. Holtz, M. of Mach'y.	1878	" " 1881, " 86	12 miles per hour.
J. D. Burr, Asst. Engr.	1879	" " 1881, " 114	8 " " "
....	1910	*Engineering News*, Jan. 13, 1910.	
....	....	Trautwine's Pocket Book, Ed. 1882, p. 412....................	
....	1910	*Engineering News*, Jan. 13, 1910.	Road locomotive and helper.
A. Mitchell, Div. Supt.	1871	Baldwin Catalogue, 1881, p. 112.	
Grafton Greenough.	1908	Baldwin Loco. Wks. Record, No. 65, p. 29..................	
Grafton Greenough.	1908	Baldwin Loco. Wks. Record, No. 65, p. 23..................	
F. E. Blaser, Div. Supt.	1910	....	Very crooked line. Uncompensated.
W. W. Stearns, Asst.Gen.Supt.	1880	Baldwin Catalogue, 1881, p. 113.	
Grafton Greenough.	1908	Baldwin Loco. Wks. Record, No. 65, p. 29..................	
Grafton Greenough	1906	Baldwin Loco. Wks. Record, No. 65, p. 23..................	

grade (as in Item 15 of Table 1) the resistance would be, gravity 4 lb. + train 4.7 lb. = 8.7 lb., against which the energy above given would carry the train through $\frac{113\,400}{8.7} = 13\,034$ ft., say, 2.5 miles, leaving 5 miles to be provided for by the steam production. Examining the items in the table having grades in excess of 10 miles, it will be noted that 16% is about all the weight on drivers which can be utilized by the current supply of steam. In Item 15 the energy derived from all sources is equivalent to 24.3%; hence the stored heat may be considered as responsible for an equivalent of 24.3% — 16% = 8.3% for a distance of 5 miles.

In proportioning grade resistance for any line, therefore, a locomotive may be counted on to utilize 24.3% of the weight on the drivers for a distance of 5 miles on a 0.002 grade without any assistance from momentum, and, in the event of an unexpected stop, should be able, as soon as a full head of steam is built up, to start the train and carry it over the grade. This is probably a maximum, considering the condition of the equipment of this Virginian Railway, as previously mentioned.

Treating Item 14 in the same way, a distance of 2 310 ft. is accounted for by momentum, leaving, say, 3.5 miles for the steam, or the length of a 0.02 grade on which a locomotive may be loaded on a basis of tractive power equal to 24.2% of the weight on the drivers.

From these figures it may be concluded that on lines having grades from 12 to 15 or more miles in length, grades of 3 to 5 miles in length may be inserted having rates 50% in excess of that of the long grades, without decreasing the capacity of the line. This statement, of course, is general in its bearings, each case being subject to its especial limitations, and subject to detailed calculations.

It may be noted that the velocity of 60 ft. per sec., assumed at the foot of the grade, is probably higher than should be expected in practice; it insures, on the other hand, that quite enough has been allowed for momentum, and that the results are conservative.

Arguments like the foregoing are always more or less treacherous; being based on statistics, they are naturally subject to material modifications in the presence of a larger array of data, therefore, material assistance in reaching practical conclusions can be given by the presentation of additional data.

Vol. XXXVI. APRIL, 1910. No. 4.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

PAPERS AND DISCUSSIONS

PRESSURE RESISTANCE AND STABILITY OF EARTH.

By J. C. Meem, M. Am. Soc. C. E.

To be Presented May 18th, 1910.

In the final discussion of the writer's paper, "The Bracing of Trenches and Tunnels, With Practical Formulas for Earth Pressures,"* certain minor experiments were noted in connection with the arching properties of sand. In the present paper it is proposed to take up again the question of earth pressures, but in more detail, and to note some further experiments and deductions therefrom, and also to consider the resistance and stability of earth as applied to piling and foundations, and the pressure on and buoyancy of subaqueous structures in soft ground.

In order to make this paper complete in itself, it will be necessary, in some instances, to include in substance some of the matter of the former paper, and indulgence is asked from those readers who may note this fact.

Experiment No. 1.—As the sand-box experiments described in the former paper were on a small scale, exception might be taken to them, and therefore the writer has made this experiment on a scale sufficiently large to be much more conclusive. As shown in Fig. 1, wooden

* *Transactions*, Am. Soc. C. E., Vol. LX, p. 1.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

abutments, 3 ft. wide, 3 ft. apart, and about 1 ft. high, were built and filled solidly with sand. Wooden walls, 3 ft. apart and 4 ft. high, were then built crossing the abutments, and solidly cleated and braced frames were placed across their ends about 2 ft. back of each abutment. A false bottom, made to slide freely up and down between the abutments, and projecting slightly beyond the walls on each side, was then blocked up snugly to the bottom edges of the sides, thus obtaining a box 3 by 4 by 7 ft., the last dimension not being important. Bolts, 44 in. long, with long threads, were run up through the false bottom and through 6 by 15 by 2-in. pine washers to nuts on the top. The box was filled with ordinary coarse sand from the trench, the sand

SECTIONS OF BOX-FRAME FOR SAND-ARCH EXPERIMENT

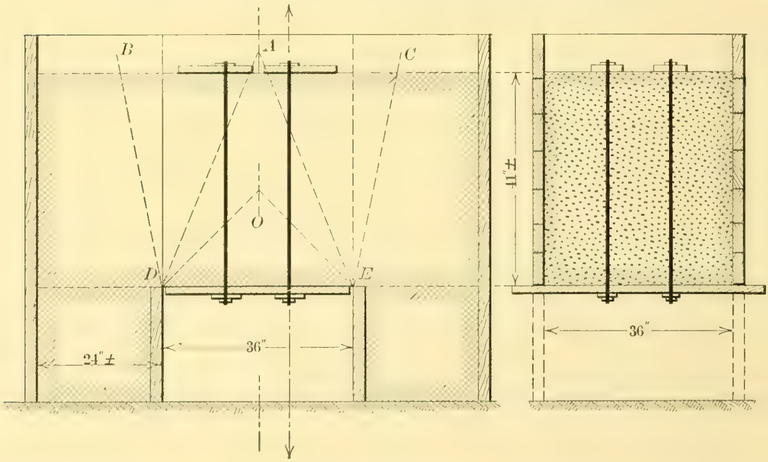


Fig. 1.

being compacted as thoroughly as possible. The ends were tightened down on the washers, which in turn bore on the compacted sand. The blocking was then knocked out from under the false bottom, and the following was noted:

As soon as the blocking was removed the bottom settled nearly 2 in., as noted in Fig. 1, Plate LXXVI, due to the initial compacting of the sand under the arching stresses. A measurement was taken from the bottom of the washers to the top of the false bottom, and it was noted as 41 in. (Fig. 1). After some three or four hours, as the arch had not been broken, it was decided to test it under greater loading, and four men were placed on it, four others standing on the

FIG. 1.—INITIAL SETTLEMENT IN 3-FT. SAND ARCH, DUE TO COMPRESSION OF MATERIAL ON REMOVING SUPPORTS FROM BOTTOM.

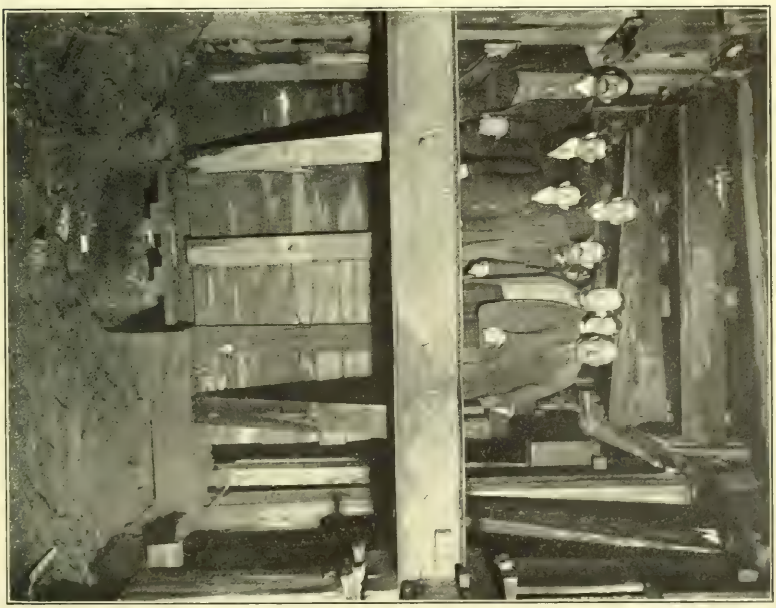


FIG. 2.—FINAL SETTLEMENT OF SAND ARCH, DUE TO COMPRESSION IN EXCESS LOADING.

haunches, as shown in Fig. 2, Plate LXXVI. Under this additional loading of about 600 lb. the bottom settled 2 in. more, or nearly 4 in. in all, due to the further compression of the sand arch. About an hour after the superimposed load had been removed, the writer jostled the box with his foot sufficiently to dislodge some of the exposed sand, when the arch at once collapsed and the bottom fell to the ground.

Referring to Fig. 2, if, instead of being ordinary sand, the block comprised within the area, *A U J V X*, had been frozen sand, there can be no reason to suppose that it would not have sustained itself, forming a perfect arch, with all material removed below the line, *V E J*, in fact, the freezing process of tunneling in soft ground is based on this well-known principle.

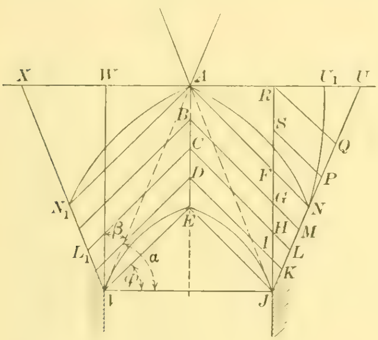


FIG. 2.

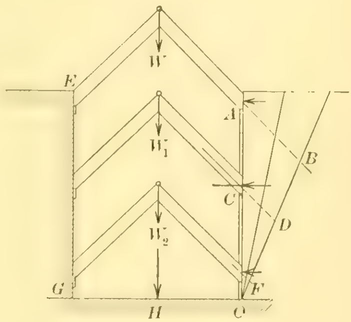


FIG. 3.

If, then, instead of removing the mass, *J E V*, it is allowed to remain and is supported from the mass above, one must concede to this mass in its normal state the same arching properties it would have had if frozen, excepting, of course, that a greater thickness of key should be allowed, to offset a greater tendency to compression in moist and dry as against frozen sand, where both are measured in a confined area.

If, in Fig. 2, $E\ V\ J = \phi =$ the angle of repose, and it be assumed that *A J*, the line bisecting the angle between that of repose and the perpendicular, measures at its intersection with the middle vertical (*A*, Fig. 2) the height which is necessary to give a sufficient thickness of key, it may be concluded that this sand arch will be self-sustaining. That is, it is assumed that the arching effect is taken up virtually within the limits of the area, $A\ N_1\ V\ E\ J\ N\ A$, thus relieving the

structure below of the stresses due to the weight or thrust of any of the material above; and that the portion of the material below $V\ E\ J$ is probably dead weight on any structure underneath, and when sustained from below forms a natural "centering" for the natural arch above. It is also probably true that the material in the areas, $X\ N_1\ A$ and $A\ N\ U$, does not add to the arching strength, more especially in those materials where cohesion may not be counted on as a factor. This is borne out by the fact that, in the experiment noted, a well-defined crack developed on the surface of the sand at about the point U_1, and extended apparently a considerable depth, assumed to be at N, where the haunch line is intersected by the slope line from A.

In this experiment the sand was good and sharp, containing some gravel, and was taken directly from the adjoining excavation. When thrown loosely in a heap, it assumed an angle of repose of about 45 degrees. It should be noted that this material when tested was not compacted as much, nor did it possess the same cohesion, as sand in its normal undisturbed condition in a bank, and for this reason it is believed that the depth of key given here is absolutely safe for all except extraordinary conditions, such as non-homogeneous material and others which may require special consideration.

Referring again to the area, $A\ N_1\ V\ J\ N\ A$, Fig. 2, it is probable that, while self-sustaining, some at least of the lower portion must derive its initial support from the "centering" below, and the writer has made the arbitrary assumption that the lower half of it is carried by the structure while the upper half is entirely independent of it, and, in making this assumption, he believes he is adding a factor of safety thereto. The area, then, which is assumed to be carried by an underground structure the depth of which is sufficient to allow the lines, $V\ A$ and $J\ A$, to intersect below the surface, is the lower half of $A\ N_1\ V\ E\ J\ N\ A$, or its equivalent, $A\ V\ E\ J\ A$, plus the area, $V\ E\ J$, or $A\ V\ J\ A$, the angle, $A\ V\ J$, being $\alpha = \frac{1}{2}(90° - \phi) + \phi = 45° + \frac{\phi}{2}$.

It is not probable that these lines of thrust or pressure transmission, $A\ N$, $D\ K$, etc., will be straight, but, for purposes of calculation, they will be assumed to be so, also, that they will act along and parallel to the lines of repose of their natural slope, and that the thrust of the earth will therefore be measured by the relation between the radius and the tangent of this angle multiplied by the weight of material

affected. The dead weight on a plane, $V J$, due to the material above, is, therefore, where

l = span or extreme width of opening = $V J$.

W = weight per cubic foot of material, and

W_1 = weight per linear foot.

$$W_1 = \frac{2 \times \frac{l}{2} \tan. \alpha \times W}{2} = \frac{1}{2}\, l \tan. \left\{ \frac{1}{2} (90^\circ - \phi) + \phi \right\} W$$

$$= \frac{l}{2} \tan. \left(45^\circ + \frac{\phi}{2}\right) W.$$

The application of the above to flat-arched or circular tunnels is very simple, except that the question of side thrust should be considered also as a factor. The thrust against the side of a tunnel in dry sand having a flat angle of repose will necessarily be greater than in very moist sand or clay, which stands at a much steeper angle, and, for the same reason, the arch thrust is greater in dryer sand and therefore the load on a tunnel structure should not be as great, the material being compact and excluding cohesion as a factor. This can be illustrated by referring to Fig. 3 in which it is seen that the flatter the position of the "rakers" keying at W_1, W_2, and W, the greater will be the side thrust at A, C, and F. It can also be illustrated by assuming that the arching material is composed of cubes of polished marble set one vertically above the other in close columns. There would then be absolutely no side thrust, but, likewise, no arching properties would be developed, and an indefinite height would probably be reached above the tunnel roof before friction enough would be developed to cause it to relieve the structure of any part of its load. Conversely, if it be assumed that the superadjacent material is composed of large bowling balls, interlocking with some degree of regularity, it can be seen that those above will form themselves into an arch over the "centering" made up of those supported directly by the roof of the structure, thus relieving the structure of any load except that due to this "centering."

If, now, the line, $A B$, in Fig. 4, be drawn so as to form with $A C$ the angle, β, to be noted later, and it be assumed that it measures the area of pressure against $A C$, and if the line, $C F$, be drawn, forming with $C G$, the angle, α, noted above, then $G F$ can be reduced in some measure by reason of the increase of $G C$ to $C B$, because the side thrust above the line, $B C$, has slightly diminished the loading above. The writer makes the arbitrary assumption that this decrease in $G F$

should equal 20% of $B\ C = F\ D_1$. If, then, the line, $B\ D_1$ be drawn, it is conceded that all the material within the area, $A\ B\ D_1\ G\ C\ A$, causes direct pressure against or upon the structure, $G\ C\ A$, the vertical lines being the ordinates of pressure due to weight, and the horizontal lines (qualified by certain ratios) being the abscissas of pressure due to thrust. An extreme measurement of this area of pressure is doubtless approximately more nearly a curve than the straight lines given, and the curve, $A\ R\ T\ I\ D_2$, is therefore drawn in to give graphically and approximately the safe area of which any

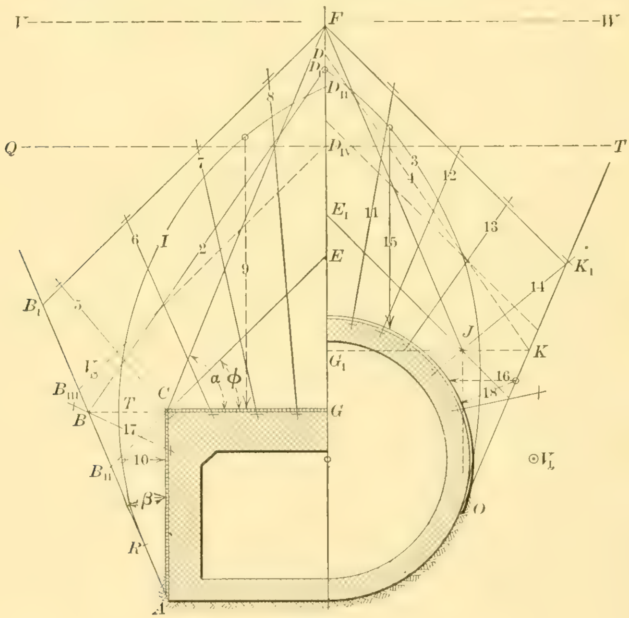


FIG. 4.

vertical ordinate, multiplied by the weight, gives the pressure on the roof at that point, and any horizontal line, or abscissa, divided by the tangent of the angle of repose and multiplied by the weight per foot, gives the pressure on the side at that point.

The practical conclusion of this whole assumption is that the material in the area, $F\ E\ C\ B\ B_1$, forms with the equivalent opposite area an arch reacting against the face, $C\ B\ B_1$, and that, as heretofore noted, the lower half (or its equivalent, $B\ D_1\ G\ B$) of the weight of this is assumed to be carried by the structure, the upper half being self-sustaining, as shown by the line, $B_{III}\ D_{IV}$ (or for absolute safety

the curved line), and therefore, if rods could be run from sheeting inside the tunnel area to a point outside the line, $F B_1$, as indicated by the lines, 5, 6, 7, 8, 11, 12, 13, etc., that the internal bracing of this tunnel could be omitted, or that the tunnel itself would be relieved of all loading, whereas these rods would be carrying some large portion at least of the weight within the area circumscribed by the curve, D_{II} I T G, and further, that a tunnel structure of the approximate dimensions shown would carry its maximum load with the surface of the ground between D_{II} and F, beyond which point the pressure would remain the same for all depths.

In calculating pressures on circular arches, the arched area should first be graphically resolved into a rectangular equivalent, as in the right half of Fig. 4, proceeding subsequently as noted.

The following instances are given as partial evidence that in ordinary ground, not submerged, the pressures do not exceed in any instance those found by the above methods, and it is very probable that similar instances or experiences have been met by every engineer engaged in soft-ground tunneling:

In building the Bay Ridge tunnel sewer, in 62d and 64th Streets, Brooklyn, the arch timber bracing shown in Fig. 1, Plate LXXVIII, was used for more than 4 000 ft., or for two-thirds of the whole 5 800 ft. called for in the contract. The external width of opening, measured at the wall-plate, averaged about 19 ft. for the 14½-ft. circular sewer and 19½ ft. for the 15-ft. sewer. The arch timber segments in the cross-section were 10 by 12-in. North Carolina pine of good grade, with 2 in. off the butt for a bearing to take up the thrust. They were set 5 ft. apart on centers, and rested on 6 by 12-in. wall-plates of the same material as noted above. The ultimate strength of this material, across the grain, when dry and in good condition, as given by the United States Forestry Department tests is about 1 000 lb. in compression. Some tests* made in 1907 by Mr. E. F. Sherman for the Charles River Dam in Boston, Mass., show that in yellow pine, which had been water-soaked for two years, checks began to open at from 388 to 581 lb. per sq. in., and that yields of ¼ in. were noted at from 600 to 1 000 lb. As the tunnel wall-plates described in this paper were subject to occasional saturation, and always to a moist atmosphere, they could never have been considered as equal to dry material. Had

* *Engineering News*, July 1st, 1909.

the full loading shown by the foregoing come on these wall-plates, they would have been subjected to a stress of about 25 tons each, or nearly one-half of their ultimate strength. In only one or two instances, covering stretches of 100 ft. in one case and 200 ft. in another, where there were large areas of quicksand sufficient to cause semi-aqueous pressure, or pockets of the same material causing eccentric loading, did these wall-plates show any signs of heavy pressure, and in many instances they were in such good condition that they could be taken out and used a second and a third time. Two especially interesting instances came under the writer's observation: In one case, due to a collapse of the internal bracing, the load of an entire section, 25 ft. long and 19 ft. wide, was carried for several hours on ribs spaced 5 ft. apart. The minimum cross-section of these ribs was 73 sq. in., and they were under a stress, as noted above, of 50 000 lb., or nearly up to the actual limit of strength of the wall-plate where the rib bore on it. When these wall-plates were examined, after replacing the internal bracing, they did not appear to have been under any unusual stress.

In another instance, for a distance of more than 700 ft., the sub-grade of the sewer was 4 ft. below the level of the water in sharp sand. In excavating for "bottoms" the water had to be pumped at the rate of more than 300 gal. per min., and it was necessary to close-sheet a trench between the wall-plates in which to place a section of "bottom." In spite of the utmost care, some ground was necessarily lost, and this was shown by the slight subsidence of the wall-plates and a loosening up of the wedges in the supports bearing on the arch timbers. During this operation of "bottoming," two men on each side were constantly employed in tightening up wedges and shims above the arch timbers. It is impossible to explain the fact that these timbers slackened (without proportionate roof settlement) by any other theory than that the arching was so nearly perfect that it relieved the bracing of a large part of the load, the ordinary loose material being held in place by the arching or wedging together of the 2-in. by 3-ft. sheeting boards in the roof, arranged in the form of a segmental arch. The material above this roof was coarse, sharp sand, through which it had been difficult to tunnel without losing ground, and it had admitted water freely after each rain until the drainage of a neighboring pond had been completed, the men never being willing to resume work until the influx of water had stopped.

FIG. 1.—NORMAL SLOPES AND STRATA OF NEWLY EXCAVATED BANKS.

FIG. 2.—NORMAL SLOPES AND STRATA OF NEWLY EXCAVATED BANKS.

The foregoing applies only to material ordinarily found under ground not subaqueous, or which cannot be classed as aqueous or semi-aqueous material. These conditions will be noted later.

The writer will take up next the question of pressures against the faces of sheeted trenches or retaining walls, in material of the same character as noted above. Referring to Fig. 2, it is not reasonable to suppose that having passed the line, *R F J,* the character of the stresses due to the thrust of the material will change, if bracing should be substituted for the material in the area, *W V J R,* or if, as in Fig. 3, canvas is rolled down along the lines, *E G* and *A O,* and if, as this section is excavated between the canvas faces, temporary struts are erected, there is no reason to believe that with properly

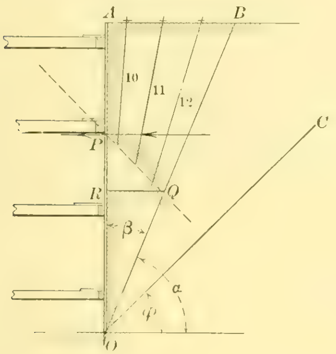


Fig. 5.

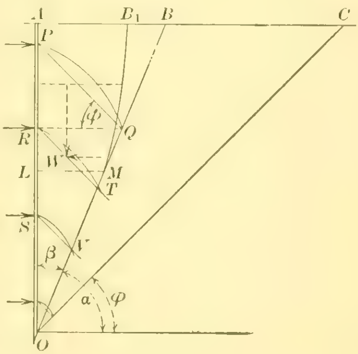


Fig. 6.

adjusted weights at W or W_2, an exact equilibrium of forces and conditions cannot be obtained. Or, again, if, as in Fig. 5, the face, *P Q*, is sheeted and rodded back to the surface, keying the rods taut, there is undoubtedly a stable condition and one which could not fail in theory or practice, nor can anyone, looking at Fig. 5, doubt that the top timbers are stressed more heavily than those at the bottom. The assumption is that the tendency of the material to slide toward the toe causes it to wedge itself between the face of the sheeting on the one hand and some plane between the sheeting and the plane of repose on the other, and that the resistance to this tendency will cause an arching thrust to be developed along or parallel to the lines, *A N, B M,* etc., Fig. 2, which are assumed to be the lines of repose, or curves approximating thereto. As the thrust is greatest in that material directly at the face, *A O*, Fig. 6, and is nothing at the plane

of repose, $C\ O$, it may be assumed arbitrarily that the line, $B\ O$, bisecting this angle divides this area into two, in one of which the weight resolves itself wholly into thrust, the other being an area of no thrust, or wholly of weight bearing on the plane of repose. Calling this line, $B\ O$, the haunch line, the thrust in the area, $A\ O\ B$, is measured by its weight divided by the tangent of the angle, $P\ Q\ R = \phi$, which is the angle of repose; that is, the thrust at any given point, $R = R\ Q \div \tan.\ \phi$.

The writer suggests that, in those materials which have steeper angles of repose than 45°, the area of pressure may be calculated as above, the thrust being computed, however, as for an angle of 45 degrees.

In calculating the total pressure due to this thrust against the retaining wall or sheeted face, there is the weight of the mass multiplied by the distance of its center of gravity vertically above the toe, or approximately:

$$\text{Area, } A\ O\ B, \times \text{ weight per unit} \times \frac{2}{3} \text{ height,}$$

where h = height,

W = weight per foot of material = 90 lb., and $\beta = \frac{90° - \phi}{2}$

P = pressure per linear foot (vertically),

$$\text{then } P = h \times \frac{h}{2} (\tan.\ \beta) \times W \times \frac{2}{3} h = \frac{1}{3} h^3 \tan.\ \beta.$$

Figs. 1 and 2, Plate LXXVII, show recently excavated banks of gravel and sand, which, standing at a general angle of 45°, were in process of "working," that is, there was continual slipping down of particles of the sand, and it may be well to note that in time, under exposure to weather conditions, these banks would finally assume a slope of about 33 degrees. They are typical, however, as showing the normal slope of freshly excavated sandy material, and a slope which may be used in ordinary calculations. The steps seen in Plate LXXVII show the different characteristics of ground in close proximity. In Fig. 2, Plate LXXVIII,* may be seen a typical bank of gravel and sand; it shows the well-defined slope of sand adjacent to and in connection with the cohesive properties of gravel.

The next points to be considered are the more difficult problems concerning subaqueous or saturated earths. The writer has made

*From "Gravel for Good Roads."

FIG. 1.—TYPES OF ARCH TIMBERS USED IN BAY RIDGE TUNNEL SEWER.

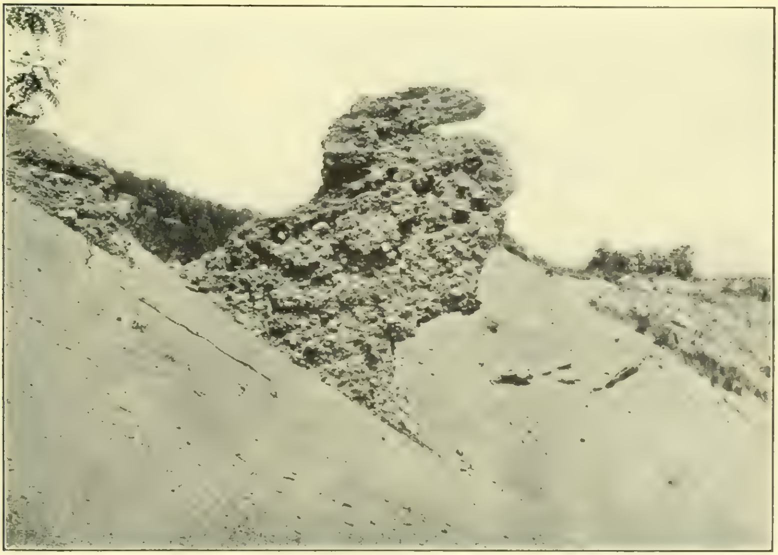


FIG. 2.—NORMAL SLOPE OF LOOSE SAND, GRAVEL, AND CEMENTED GRAVEL, IN CLOSE PROXIMITY.

some experiments which appear to be conclusive, showing that, except in pure quicksand or wholly aqueous material, as described later, the earth and water pressures act independently of each other.

For a better understanding of the scope and purpose of this paper, the writer divides supersaturated or subaqueous materials into three classes:

Class A.—Firm materials, such as coarse and fine gravels, gravel and sands mixed, coarse sands, and fine sands in which there is not a large proportion of fine material, such as loam, clay, or pure quicksand.

Class B.—Semi-aqueous materials, such as fine sands in which there is a large proportion of clay, etc., pure clays, silts, peats, etc.

Class C.—Aqueous materials, such as pure quicksands, in which the solid matter is so finely divided that it is amorphous and virtually held in suspension, oils, quicksilver, etc.

Here it may be stated that the term, "quicksand," is so illusive that a true definition of it is badly needed. Many engineers call quicksand any sand which flows under the influence of water in motion. The writer believes the term should be applied only to material so "soupy" that its properties are practically the same as water under static conditions, it being understood that any material may be unstable under the influence of water at sufficiently high velocities, and that it is with a static condition, or one approximately so, that this paper deals.

A clear understanding of the firm materials noted in Class A will lead to a better solution of problems dealing with those under Class B, as it is to this Class A that the experiments largely relate.

The experiments noted below were made with varying material, though the principal type used was a fine sand under the conditions in which it is ordinarily found in excavations, with less than 40% voids and less than 10% of very fine material.

Experiment No. 2.—The first of these experiments, which in this series will be called No. 2, was simple, and was made in order to show that this material does not flow readily under ordinary conditions, when not coupled with the discharge of water under high velocity. A bucket 12 in. in diameter, containing another bucket 9 in. in diameter, was used. A 6 by 6-in. hole was cut in the bottom of the inner bucket. About 3 in. of sand was first placed in the bottom of the larger bucket and it was partly filled with water. The inside

bucket was then given a false bottom and partly filled with wet sand, resting on the sand in the larger bucket. Both were filled with water and the weight, *W*, Fig. 7, on the arm was shifted until it balanced the weight of the inside bucket in the water, the distance of the weight, *W*, from the pivot being noted. The false bottom was then removed and the inside bucket, resting on the sand in the larger one, was partly filled with sand and both were filled with water, the conditions at the point of weighing being exactly the same, except that the false bottom was removed, leaving the sand in contact through the 6 by 6-in. opening. It is readily seen that, if the sand had possessed the aqueous properties sometimes attributed to sand under water, that in the inside bucket would have flowed out through the square hole in the bottom, allowing it to be lifted by any weight in excess of the actual weight of the bucket, less its buoyancy, as would be the case if

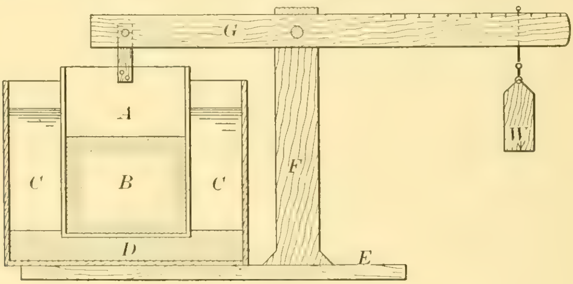


FIG. 7.

it contained only water instead of sand and water. It was found, however, that the weight, resting at a distance of more than nine-tenths of the original distance from the pivot, would not raise the inside bucket. On lifting this inside bucket bodily, however, the water at once forced the sand out through the bottom, leaving a hole almost exactly the shape and size of the bottom orifice, as shown in Fig. 1, Plate LXXIX. It should be stated that, in each case, the sand was put in in small handfuls and thoroughly mixed with water, but not packed, and allowed to stand for some time before the experiments were tried, to insure the compactness of ordinary conditions. It is seen from Fig. 1, Plate LXXIX, that the sand was stable enough to allow the bucket to be put on its side for the moment of being photographed, although it had been pulled out of the water a little less than 3 min.

FIG. 1.—EXPERIMENT SHOWING PROPERTIES OF SAND.

FIG. 2.—SAND PUSHED UP FROM BOWL BY WATER PRESSURE THROUGH GOOSE-NECK.

Experiment No. 3.—In order to show that the arching properties of sand are not destroyed under subaqueous conditions, a small sand-box, having a capacity of about 1 cu. ft., and similar to that described in Experiment No. 1, was made. The bottom was cut out, with the exception of a $\frac{3}{4}$-in projection on two sides, and a false bottom was placed below and outside of the original bottom, with bolts running through it, keying to washers on top of the sand, with which the box was partially filled. One side of the box contained a glass front, in order that conditions of saturation could be observed. The box of sand was then filled with water and, after saturation had been completed and the nuts and washers had been tightened down, the box was lifted off the floor. There was found to be no tendency whatever for the bottom to fall away, showing conclusively that the arching properties had not been destroyed by the saturation of the sand.

The next three experiments were intended to show the relative pressure over any given area in contact with the water in the one case or sand and water in the other.

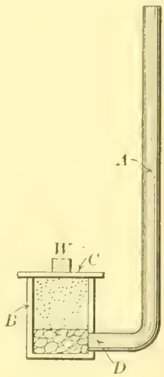


FIG. 8.

Experiment No. 4.—The apparatus for this experiment consisted of a 3-in. pipe about 4-in. long and connected with a $\frac{3}{4}$-in. goose-neck pipe 17 in. high above the top of the bowl shown in Fig. 8 and in Fig. 2, Plate LXXIX. A loose rubber valve was intended to be seated on the upper face of the machined edge of the bowl and weighted down sufficiently to balance it against a head of water corresponding to the 17-in. head in the goose-neck. The bowl was then to be filled with sand and the difference, if any, noted between the weight required to hold the flap-valve down under the same head of water flowing through the sand. The results of this experiment were not conclusive, owing to the difficulty of making contact over the whole area of the sand and the rim of the bowl at the same time. At times, for instance, less than 1 lb. would hold back the water indefinitely, while, again, 2 or 3 lb. would be required as opposed to the $4\frac{1}{2}$ lb. approximate pressure required to hold down the clear water. Again, at times the water would not flow through the neck at all, even after several hours, and after increasing the head by attaching a longer rubber tube

thereto. In view of these conditions, this experiment would not be noted here, except that it unexpectedly developed one interesting fact. In order to insure against a stoppage of water, as above referred to, gravel was first put into the bottom of the bowl and the flap-valve was then rubbed down and held tightly while the pipe was filled. On being released, the pressure of water invariably forced out the whole body of sand, as shown in Fig. 2, Plate LXXIX. Care was taken to see that the sand was saturated in each case, and the experiment was repeated numberless times, and invariably with the same result. The sand contained about 40% of voids. The deduction from this experiment is that the pressure of water is against rather than through sand and that any excess of voids occurring adjacent to a face against which there is pressure of water will be filled with sand, excepting in so far, of course, as the normal existing voids allow the pressure of the water to be transmitted through them.

If, then, the covering of sand over a structure is sufficiently heavy to allow arching action to be set up, the structure against which the pressure is applied must be relieved of much of the pressure of water against the area of sand not constituted as voids acting outside of the arching area. This is confirmed by the two following experiments:

Experiment No. 5.—The same apparatus was used here as in Experiment No. 2, Fig. 7, except that the inside bucket had a solid bottom. The inside and outside buckets were filled with water and the point was noted at which the weight would balance the inside bucket at a point some 3 in. off the bottom of the outside bucket. This point was measured, and the bottom of the larger bucket was covered over with sand so that in setting solidly in the sand the inside bucket would occupy the same relative position as it did in the water. The same weight was then applied and would not begin to lift the inner bucket. For instance, in the first part of the experiment the weight stood at 12 in. from the pivot, while in the next step the weight, standing at the end of the bar, had no effect, and considerable external pressure had to be exerted before the bucket could be lifted. Immediately after it was relieved, however, the weight at 12 in. would hold it clear of the sand. No attempt was made to work the bucket into the sand; the sand was leveled up and the bucket was seated on it, turned once or twice to insure contact, and then allowed to stand for some time before making the experiment. No attempt was made to establish the rela-

tionship between sands of varying voids, the general fact only being established, by a sufficient number of experiments, that the weight required to lift the bucket was more than double in sand having 40% of voids than that required to lift the bucket in water only.

Experiment No. 6.—The apparatus for this experiment consisted essentially of a hydraulic chamber about 8 in. in diameter and 1 ft. high, the top being removable and containing a collar with suitable packing, through which a 2½-in. piston moved freely up and down, the whole being similar to the cylinder and piston of a large hydraulic jack, as shown in Fig. 1, Plate LXXX. Just below the collar and

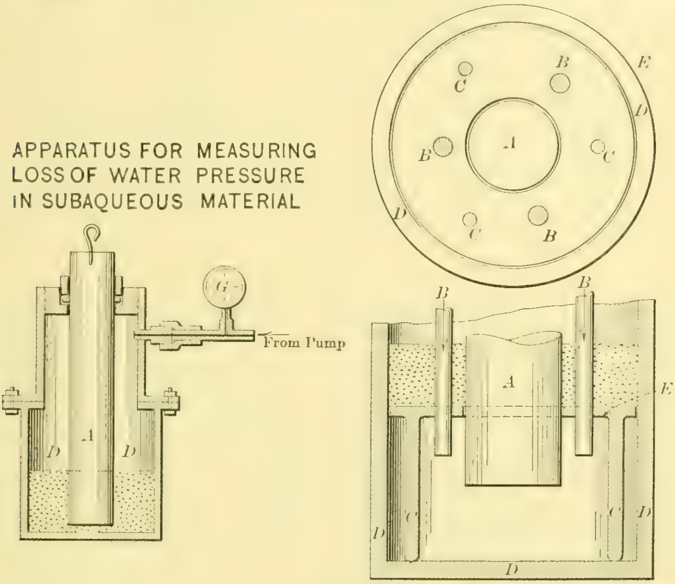


FIG. 9.

above the chamber there was a ½-in. inlet leading to a copper pipe and thence to a high-pressure pump. Attached to this there was a gauge to show the pressure obtained in the chamber, all as shown in Fig. 9. The purpose of the apparatus was to test the difference in pressure on any object submerged in clear water and on the same object buried in the sand under water. It is readily seen that, if pressure be applied to the water in this chamber, the amount of pressure (as measured by the gauge) necessary to lift the piston will be that due to the weight of the piston, less its displacement, plus the friction of the piston in the collar.

Now, if for any reason the bottom area of the piston against which the water pressure acts be reduced, it will necessarily require a proportionate amount of increase in the pressure to lift this piston. If, therefore, it is found that 10 lb., for illustration, be required to lift the piston when plunged in clear water, and 20 lb. be required to lift it when buried in sand, it can be assumed at once that the area of the piston has been reduced 50% by being buried in the sand, eliminating the question of the friction of the sand itself around the piston. In order to determine what this friction might be, the writer arranged a table standing on legs above the bottom of the chamber, allowing the piston to move freely through a hole in its center. Through this table pipes were entered (as shown in part of Fig. 9). The whole was then placed in the chamber with the piston in place, and the area above was filled with sand and water. It is thus seen that, the end of the piston being free and in clear water, the difference, if any, between the pressure required to lift the piston when in clear water alone and in the case thus noted, where it was surrounded by sand, would measure the friction of the sand on the piston. After several trials of this, however, it was clearly seen that the friction was too slight to be noted accurately by a gauge registering single pounds, that is, with a piston in contact with 6 in. of sand vertically, a friction of 25 lb. per sq. ft. would only require an increase of 1.8 lb. on the gauge. It is therefore assumed that the friction on so small a piston in sand need not be considered as a material factor in the experiments made.

The piston was plunged into clear water, and it was found that the pressure required to lift it was about 4 lb. The cap was then taken off, a depth of about 2 in. of sand was placed in the bottom of the chamber, and then the piston was set in place and surrounded by sand to a depth of some 6 in., water being added so that the sand was completely saturated. This was allowed to stand until it had regained the stability of ordinary sand in place, whereupon the cap with the collar bearing was set in place over the piston, the machine was coupled up, and the pump was started. A series of four experiments, extending over a period of two or three days, gave the following results:

Test 1.—The piston began to move at a pressure of 25 lb. The pressure gradually dropped to $7\frac{1}{2}$ lb., at which point, apparently, it came out of the sand, and continued at $7\frac{1}{2}$ lb. during the remainder of the test.

FIG. 1.—APPARATUS FOR MEASURING LOSS OF PRESSURE IN SUBAQUEOUS MATERIALS.

FIG. 2. RAISING ROOF OF BATTERY TUBES, IN BROOKLYN, BY "BLEEDING" SAND THROUGH DISPLACED PLATES.

Test 2.—The piston was plunged back into the sand, without removing the cap, and allowed to stand for about 2 hours. No attempt was made to pack the sand or to see its condition around the piston, it being presumed, however, that it had reasonable time to get a fair amount of set. At slightly above 20 lb. the piston began to move, and as soon as a pocket of water accumulated behind the piston the pressure immediately dropped to 9 lb. and continued at this point until it came out of the sand.

Test 3.—The piston was plunged into the sand and hammered down without waiting for the sand to come to a definite set. In this case the initial pressure shown by the gauge was 17½ lb., which immediately dropped to 8 lb. as soon as the piston had moved sufficiently far to allow water to accumulate below it.

Test 4.—The cap was again removed, the piston set up in place, the sand compacted around it in approximately the same condition it would have had if the sand had been in place underground; the cap was then set in place and, after an hour, the pump was started. The pressure registered was 25 lb. and extended over a period of several seconds before there was any movement in the piston. The piston responded finally without any increase of pressure, and, after lifting an inch or two, the pressure gradually dropped to 10 lb., where it remained until the piston came out of the sand.

The sum and average of these tests shows a relation of 22 lb. for the piston in sand to about 8½ lb. as soon as the volume of water had accumulated below it, which would correspond very closely to a sand containing 40% of voids, which was the characteristic of the sand used in this experiment.

The conclusions from this experiment appear to be absolutely final in illustrating the pressure due to water on a tunnel buried in sand, either on the arch above or on the sides or bottom, as well as the buoyant effect upon the tunnel bottom under the same conditions.

While the apparatus would have to be designed and built on a much larger scale in order to measure accurately the pressures due to sands and earths of varying characteristics, it appears to be conclusive in showing the principle, and near enough to the theoretical value to be taken for practical purposes in designing structures against water pressures when buried in sand or earth.

It should be carefully noted that the friction of the water through sand, which is always a large factor in subaqueous construction, is

virtually eliminated here, as the water pressure has to be transmitted only some 6 or 8 in. to actuate the base of the piston, whereas in a tunnel only half submerged this distance might be as many feet, and would be a considerable factor.

It should be noted also that although the area subject to pressure is diminished, the pressure on the area remaining corresponds to the full hydrostatic head, as would be shown by the pressure on an air gauge required to hold back the water, except, of course, as it may be diminished more or less by friction.

The writer understands that experiments of a similar nature and with similar apparatus have been tried on clays and peats with results considerably higher; that is, in one case, there was a pressure of 40 lb. before the piston started to move.

The following is given, in part, as an analysis and explanation of the above experiments and notes:

It is well known that if lead be placed in a hydraulic press and subjected to a sufficient pressure it will exhibit properties somewhat similar to soft clay or quicksand under pressure. It will flow out of an orifice or more than one orifice at the same pressure. This is due to the fact that practically voids do not exist and that the pressure is so great, compared with the molecular cohesion, that the latter is virtually nullified. It is also theoretically true that solid stone under infinitely high pressure may be liquefied. If in the cylinder of a hydraulic press there be put a certain quantity of cobblestones, leaving a clearance between the top of the stone and the piston, and if this space, together with the voids, be filled with water and subjected to a great pressure, the sides or the walls of the cylinder are acted on by two pressures, one almost negligible, where they are in contact with the stone, restraining the tendency of the stone to roll or slide outward, and the other due to the pressure of the water over the area against which there is no contact of stone. That this area of contact should be deducted from the pressure area can be clearly shown by assuming another cylinder with cross-sticks jammed into it, as shown in Fig. 10. A glance at this figure will show that there is no aqueous pressure on the walls of the cylinder with which the ends of the sticks come in contact and the loss of the pressure against the walls due to this is equal to the least sectional area of the stick or tube either at the point of contact or intermediate thereto.

Following this reasoning, in Fig. 11 it is found that an equivalent area may be deducted covering the least area of continuous contact of the cobblestones, as shown along the dotted lines in the right half of the figure. Returning, if, when the pressure is applied, an orifice be made in the cylinder, the water will at once flow out under pressure, allowing the piston to come in contact with the cobblestones. If the flow of the water were controlled, so as to stop it at the point where the stone and water are both under direct pressure, it would be found that the pressures were totally independent of each other. The aqueous pressure, for instance, would be equal at every point, while the pressure on the stone would be through and along the lines of contact. If this contact was reasonably well made and covered 40% of the area, one would expect the stone, independently of the water, to

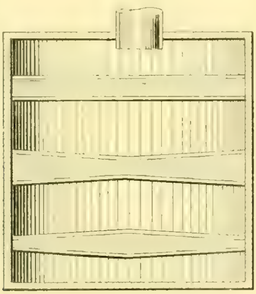


Fig. 10.

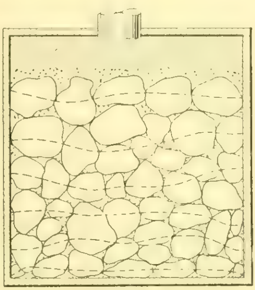


Fig. 11.

stand 40% of the pressure which a full area of solid stone would stand. If this pressure should be enormously increased after excluding the water, it would finally result in crushing the stone into a solid mass; and if the pressure should be increased indefinitely, some theoretical point would be reached, as above noted, where the stone would eventually be liquefied and would assume liquid properties.

The same general reasoning applies to pure sand, sand being in effect cobblestones in miniature. In pressing the piston down on dry sand it will be displaced into every existing abnormal void, but will be displaced into these voids rather than pressed into them, in the true definition of the word, and while it would flow out of an orifice in the sides or bottom, allowing the piston to be forced down as in a sand-jack, it would not flow out of an orifice in the top of the piston, except under pressures so abnormally high as to make the mass theoretically

aqueous. If the positions of cylinder and piston be reversed, the piston pointing vertically upward and the sand "bled" into an orifice in or through it, the void caused by the outflow of this sand would be filled by sand displaced by the piston pressing upward rather than by sand from above.

It was the knowledge of this principle which enabled the contractors to jack up successfully the roof of a long section of the cast-iron lined tubes under Joralemon Street in Brooklyn, in connection with the reconstruction of the Battery tubes at that point, the method of operation, as partly shown in Fig. 2, Plate LXXX, being to cut through a section of the roof, 4 by 10 ft. in area, through which holes were drilled and through which again the sand was "bled," heavy pressure being applied from below through the medium of hydraulic jacks. By a careful manipulation of both these operations, sections of the roof of the above dimensions were eventually raised the required height of 30 in. and permanently braced there in a single shift.

If water in excess be put into a cylinder containing sand, and pressure be applied thereto, the water, if allowed to flow out of an orifice, will carry with it a certain quantity of sand, according to the velocity, and the observation of this might easily give rise to the erroneous impression that the sand, as well as the water, was flowing out under pressure, and, as heretofore stated, has caused many engineers and contractors to apply the term "quicksand" to any sand flowing through an orifice with water.

Sand in its natural bed always contains some fine material, and where this is largely less than the percentage of voids, it has no material effect on the pressure exerted by the sand with or without water, as above noted. If, however, this fine material be largely in excess of the voids, it allows greater initial compression to take place when dry, and allows to be set up a certain amount of hydraulic action when saturated. If the base of the material be sand and the fill be so-called quicksand in excess of the voids, pressure will cause the quicksand to set up hydraulic action, and the action of the piston will appear to be similar to that of a piston acting on purely aqueous material.

Just here the writer desires to protest against considering semi-aqueous masses, such as soupy sands, soft concrete, etc., as exerting hydrostatic pressure due to their weight in bulk instead of to the

specific gravity of the basic liquid. For instance, resorting again to the illustration of cubes and spheres, it may be assumed that a cubical receptacle has been partly filled with small cubes of polished marble, piled vertically in columns. When this receptacle is filled with liquid around the piles of cubes there will be no pressure on the sides except that due to the hydrostatic pressure of the water at $62\frac{1}{2}$ lb. The bottom, however, will resist a combined pressure due to the water and the weight of the cubes. Again, assume that the receptacle is filled with small spheres, such as marbles, and that water is then poured in. The pressure due to the weight of the solids on the bottom is relieved by the loss in weight of the marbles due to the water, and also to the tendency of the marbles to arch over the bottom, and while the pressure on the sides is increased by this amount of thrust, the aqueous pressure is still that of a liquid at $62\frac{1}{2}$ lb., and it is inconceivable that some engineers, in calculating the thrust of aqueous masses, speak of it as a liquid weighing, say, 120 or 150 lb. per cu. ft.; as well might they expect to anchor spherical copper floats in front of a bulkhead and expect the hydrostatic pressure against this bulkhead to be diminished because the actual volume and weight of the water directly in front of the bulkhead has been diminished. Those who have had experience in tying narrow deep forms for concrete with small wires or bolts and quickly filling them with liquid concrete, must realize that no such pressures are ever developed as would correspond to liquids of 150 lb. per cu. ft. If the solid material in any liquid is agitated so that it is virtually in suspension, it cannot add to the pressure, and if allowed to subside it acts as a solid, independently of the water contained with it, although the water may change somewhat the properties of the material, by increasing or changing its cohesion, angle of repose, etc. That is, in substance, those particles which rest solidly on the bottom and are in contact to the top of the solid material, do not derive any buoyancy from the water, while those particles not in contact with the bottom directly or through other particles, lose just so much weight through buoyancy. If, then, the vertical depth of the earthy particles or sand above the bottom is so small that the arching effect against the sides is negligible, the full weight of the particles in contact, directly or vicariously, with the bottom acts as pressure on the bottom, while the full pressure of the water acts through the voids or on them, or is transmitted through material in contact with the bottom.

Referring now to materials such as clays, peats, and other soft or plastic materials, it is idle to assume that these do not possess pressure-resisting and arching properties. For instance, a soft clay arch of larger dimensions, under the condition described early in this paper, would undoubtedly stand if the rods supporting the intrados of the arch were keyed back to washers covering a sufficiently large area.

The fact that compressed air can be used at all in tunnel work is evidence that semi-aqueous materials have arching properties, and the fact that "blows" usually occur in light cover is further evidence of it.

When air pressure is used to hold back the water in faces of large area, bracing has to be resorted to. This again shows that while full hydrostatic pressure is required to hold back the water, the pressure of the earth is in a measure independent of it.

In a peaty or boggy material there is a condition somewhat different, but sufficiently allied to the soft clayey or soupy sands to place it under the same head in ordinary practice. It is undoubtedly true that piles can be driven to an indefinite depth in this material, and it is also true that the action of the pile is to displace rather than compress, as shown by the fact of driving portions of the tunnels under the North River for long distances without opening the doors of the shield or removing any of the material. The case of filling in bogs or marshes, causing them to sink at the point of filling and rise elsewhere, is readily explained by the fact that the water is confined in the interstices of the material, admitting of displacement but no compression.

The application of the above to pressures over tunnels in materials of Class A is that the sand or solid matter is virtually assumed to be a series of columns with their bases in such intimate contact with the tunnel roof that water cannot exert pressure on the tunnel or buoyancy on the sand at the point of contact, and that if these columns are sufficiently deep to have their upper portions wholly or partially carried by the arching or wedging action, the pressure of any water on their surfaces is not transferred to the tunnel, and the only aqueous pressure is that which acts on the tunnel between the assumed columns or through the voids.

Let l = exterior width of tunnel,

δ = depth of cover, as :

D_W = depth, water to roof,

D_E = " earth to roof,

D_X = " of cover of earth necessary to arching stability,

that is:

$$D_X = \frac{l}{2}\left(\tan.\left\{\frac{90^\circ - \phi}{2}\right\} + \phi\right) = \frac{l}{2}\tan.\left(45^\circ + \frac{\phi}{2}\right),$$

where ϕ = angle of repose,

and $D_W > D_E > D_X$.

Then the pressure on any square foot of roof, as V_P, as at the base of any vertical ordinate, as G in Fig. 2, $= V_O$,

W_E = weight per cubic foot of earth (90 lb.),

W_W = " " " " " water ($62\frac{1}{2}$ lb.), we have

$$V_P = V_O \times W_E + D_W \times W_W \times 0.40 = V_O \times 90 + D_W \times 62\tfrac{1}{2} \times 0.4$$
$$= V_O\ 90 + D_W \times 25.$$

And for horizontal pressure:

P_h = the horizontal pressure at any abscissa (10), Fig. 2, $= A_{10}$ at depth of water D_{W_1} is

$$P_h = \frac{A_{10} \times 90}{\tan.\ \phi} + D_{W_1} \times 62\tfrac{1}{2} \times 0.4 = \frac{A_{10} \times 90}{\tan.\ \phi} + D_{W_1} \times 25.$$

The only question of serious doubt is at just what depth the sand is incapable of arching itself, but, for purposes of safety, the writer has put this at the point, F, as noted above, $= D_X$, although he believes that experiments on a large scale would show it to be nearer 0.67 D_X, above which the placing of additional back-fill will lighten the load on the structure.

We have, then, for $D_E < D_X$, the weight of the total prism of the earth plus the water in the voids, plus the added pressure of the water above the earth prism, that is:

The pressure per square foot at the base of any vertical ordinate $= V_P$

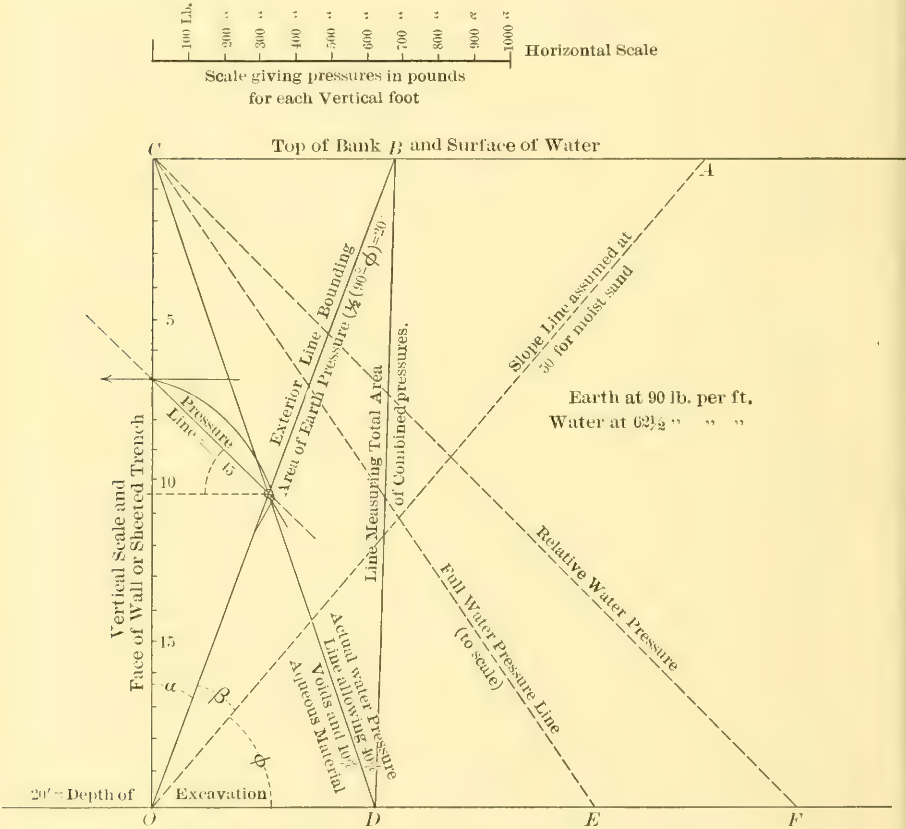
$$V_P = D_E \times 90 + D_E \times 62\tfrac{1}{2} \times 0.40 + (D_W - D_E) \times 62\tfrac{1}{2}.$$

To those who may contend that water acting through so shallow a prism of earth would exert full pressure over the full area of the tunnel, it may be stated that the water cannot maintain pressure over the whole area without likewise giving buoyancy to the sand previously assumed to be in columns, in which case there is the total weight of the water plus the weight of the prism of earth, less its buoyancy in water, that is

$$V_P = D \quad \times 62\tfrac{1}{2} + D \quad \times (90 - 62\tfrac{1}{2}),$$

which, by comparison with the former method, would appear to be less safe in its reasoning.

Next is the question of pressure against a wall or braced trench for materials under Class A. The pressure of sand is first calculated independently, as shown in Fig. 6. Reducing this to a basis of 100 lb.



COMBINED EARTH AND WATER PRESSURES.

FIG. 12.

for each division of the scale measured horizontally, as shown, gives the line, B O, Fig. 12, measuring the outside limit of pressure due to the earth, the horizontal distance at any point between this line and the vertical face equalling the pressure against that face divided by the tangent of the angle of repose, which in this case is assumed to be 45°, equalling unity. If the water pressure line, C F, is drawn, it

shows the relative pressure of the water. In order to reduce this to the scale of 100 lb. horizontal measurement, the line, *C E*, is drawn, representing the water pressure to scale, that is, so that each horizontal measurement of the scale gives the pressure on the face at that point; and, allowing 50% for voids, halving this area gives the line, *C D*, between which and the vertical face any horizontal line measures the water pressure. Extending these pressure areas where they overlap gives the line, *B D*, which represents the total pressure against the face, measured horizontally.

Next, as to the question of buoyancy in Class A materials. If a submerged structure rests firmly on a bottom of more or less firm sand, its buoyancy, as indicated by the experiments, will only be a percentage of its buoyancy in pure water, corresponding to the voids in the sand. In practice, however, an attempt to show this condition will fail, owing to the fact that in such a structure the water will almost immediately work under the edge and bottom, and cause the structure to rise, and the test can only be made by measuring the difference in uplift in a heavier-than-water structure, as shown in Experiment No. 5. For, if a structure lighter than the displaced water be buried in sand sufficiently deep to insure it against the influx of large volumes of water below, it will not rise. That this is not due entirely to the friction of the solid material on the sides has been demonstrated by the observation of subaqueous structures, which always tend to subside rather than to lift during or following disturbance of the surrounding earth.

The following is quoted from the paper by Charles M. Jacobs, M. Am. Soc. C. E., on the North River Division of the Pennsylvania Railroad Tunnels:*

"There was considerable subsidence in the tunnels during construction and lining, amounting to an average of 0.34 ft. between the bulkhead lines. This settlement has been constantly decreasing since construction, and appears to have been due almost entirely to the disturbances of the surrounding materials during construction. The silt weighs about 100 lb. per cu. ft. * * * and contains about 38% of water. It was found that whenever this material was disturbed outside the tunnels a displacement of the tunnels followed."

This in substance confirms observations made in the Battery tubes that subsidence of the structure followed disturbance of the outside

* *Proceedings*, Am. Soc. C. E., for January, 1910.

material, although theoretically the tubes were buoyant in the aqueous material.

The writer would urge, however, that, in all cases of submerged structures only partially buried in solid material, excess weighting be used to cover the contingencies of vibration, oscillation, etc., to which such structures may be subjected and which may ultimately allow leads of water to work their way underneath.

On the other hand, he urges that, in cases of floor areas of deeply submerged structures, such as tunnels or cellars, the pressure to be resisted should be assumed to be only slightly in excess of that corresponding to the pressure due to the water through the voids.

The question of pressure, etc., in Class B, or semi-aqueous materials will be considered next. Of these materials, as already shown, there are two types: (*a*) sand in which the so-called quicksand is largely in excess of any normal voids, and (*b*) plastic and viscous materials. The writer believes that these materials should be treated as mixtures of solid and watery particles, in the first of which the quicksand, or aqueous portion, being virtually in suspension, may be treated as water, and it must be concluded that the action here will be similar to that of sand and pure water, giving a larger value to the properties of water than actually exists. If, for instance, it should be found that such a mixture contained 40% of pure water, the writer would estimate its pressure on or against a structure as (*a*) that of a moist sand standing at a steep angle of repose, and (*b*) that of clear water, an allowance of 60% of the total volume being assumed, and the sum of these two results giving the total pressure. Until more definite data can be obtained by experiments on a larger scale, this assumed value of 60% of the total volume for the aqueous portion may be taken for all conditions of semi-aqueous materials, except, of course, where the solid and aqueous particles may be clearly defined, the pressures being computed as described in the preceding pages.

As to the question of pure quicksand (if such there be) and other aqueous materials of Class C, such as water, oil, mercury, etc., it has already been shown that they are to be considered as liquids of their normal specific gravity; that is, in calculating the air pressure necessary to displace them, one should consider their specific gravity only, as a factor, and not the total weight per volume including any impurities which they might contain undissolved.

In order to have a clearer conception of aqueous and semi-aqueous materials and their action, they must be viewed under conditions not ordinarily apparent. For instance, ideas of so-called quicksand are largely drawn from seeing structures sinking into it, or from observing it flowing through voids in the sheeting or casing. The action of sand and water under pressure is viewed during or after a slump, when the damage is being done, or has been done, whereas the correct view-point is under static conditions, before the slump takes place.

The following is quoted from the report of Mr. C. M. Jacobs, Chief Engineer of the East River Gas Tunnel, built in 1892-93:

"We found that the material which had heretofore been firm or stiff had, under erosion, obtained a soup-like consistency, and that a huge cavity some 3 ft. wide and 26 ft. deep had been washed up toward the river bed."

This would probably be a fair description of much of the material of this class met with in such work, if compressed air had not been used. The writer believes that in soft material surrounding submerged structures the water actually contained in the voids is not infrequently, after a prolonged period of rest, cut off absolutely from its sources of pressure and that contact with these sources of pressure will not again be resumed until a leak takes place through the structure; and, even when there is a small flow or trickling of water through such material, it confines itself to certain paths or channels, and is largely excluded from the general mass.

The broad principle of the bearing power of soil has been made the subject of too many experiments and too much controversy to be considered in a paper which is intended to be a description of experiments and observed data and notes therefrom. The writer is of the opinion, however, that entirely too little attention has been given to this bearing power of the soil; that while progress has been made in our knowledge of all classes of materials for structures, very little has been done which leads to any real knowledge of the material on which the foundation rests. For instance, it is inconceivable that 1 or 2 tons may sometimes be allowed on a square foot of soft clay, while the load on firm gravel is limited to from 4 to 6 tons. The writer's practical observations have convinced him that it is frequently much safer to put four times 6 tons on a square foot of gravel than it is to put one-fourth of 2 tons on a square foot of soft clay.

In connection with the bearing power of soil, the writer also believes that too little study has been given to the questions of the lateral pressure of earth, and he desires to quote here from some experiments described in a book* published in England in 1876, to which his attention has recently been called. This book appears to have been intended for young people, but it is of interest to note the following quotations from a chapter entitled "Sand." This chapter begins by stating that:

"During the course of a lecture on the Suez Canal by Mr. John H. Pepper, which was delivered nightly by him at the Polytechnic Institute in London, he illustrated his lecture by some experiments designed to exhibit certain properties of sand, which had reference to the construction of the Suez Canal, and it is stated that though the properties in question were by no means to be classed among recent discoveries, the experiments were novel in form and served to interest the public audience."

Further quotation follows:

"When the Suez Canal was projected, many prophesied evil to the undertaking, from the sand in the desert being drifted by the wind into the canal, and others were apprehensive that where the canal was cut through the sand the bottom would be pushed up by the pressure on the banks * * *.

"The principle of lateral pressure may now be strikingly illustrated by taking an American wooden pail and, having previously cut a large circular hole in the bottom, this is now covered with fine tissue paper, which should be carefully pasted on to prevent the particles of sand from flowing through the small openings between the paper and the wood * * * and being placed upright and rapidly filled with sand, it may be carried about by the handle without the slightest fear of the weight of the sand breaking through the thin medium. * * *

"Probably one of the most convincing experiments is that which may be formed with a cylindrical tube 18 in. long and 2 in. in diameter, open at both ends. A piece of tissue paper is carefully pasted on one end, so that when dry no cracks or interstices are left. The tube is filled with dry sand to a height of say 12 in. In the upper part is inserted a solid plug of wood 12 in. long and of the same or very nearly the same diameter as the inside of the tube, so that it will move freely up and down like the piston of an air pump. The tube, sand, and piston being arranged as described, may now be held by an assistant and the demonstrator, taking a sledge hammer,

* "Discoveries and Inventions of the Nineteenth Century," by Robert Routledge, Assistant Examiner in Chemistry and in Natural Philosophy to the University of London.

may proceed to strike steadily on the end of the piston and, although the paper will bulge out a little, the force of the blow will not break it.

"If the assistant holding the tube allows it to jerk or rebound after each blow of the hammer, the paper may break, because air and sand are driven down by the succeeding blow, and therefore it must be held steadily so that the piston bears fairly on the sand each time.

"A still more conclusive and striking experiment may be shown with a framework of metal constructed to represent a pail, the sides of which are closed up by pasting sheets of tissue paper inside and over the lower part. As before demonstrated, when a quantity of sand is poured into the pail the tissue paper casing at the bottom does not break, but if a sufficient quantity is used the sides formed of tissue paper bulge out and usually give way in consequence of the lateral pressure exerted by the particles of sand."

The writer has made the second experiment noted, with special apparatus, and finds that with tissue paper over the bottom of a 2-in. pipe, 15 in. long, it will stand the blow of a heavy sledge hammer. transmitted through a wooden piston, at least once and sometimes two or three times, while heavy blows given with a lighter hammer have no effect at all. That this is not due in any large measure to inertia can be shown by the fact that more than 200 lb. can safely be put on top of the wooden piston. It cannot be accounted for entirely by the friction, as the removal of the paper allows the sand to drop in a mass. The explanation is that the pressure is transmitted laterally to the sides, and as the friction is directly proportional to the pressure, the load or effect of the blow is carried by the proportional increase in the friction, and any diaphragm which will carry the direct bottom load will not have its stresses largely increased by any greater loading on top.

The writer believes that experiments will show that in a sand-jack the tendency will be for the sides to burst rather than the bottom, and that the outflow from an orifice at or near the bottom is not either greatly retarded or accelerated by ordinary pressure on top. The occurrence of abnormal voids, however, causes the sand to be displaced into them.

The important consideration of this paper is that all the experiments and observations noted point conclusively to the fact that pressure is transmitted laterally through ground, most probably along or nearly parallel to the angles of repose, or in cases of rock or stiff material, along a line which, until more conclusive experiments are

made, may be taken as a mean between the horizontal and vertical, or approximately 45 degrees. There is no reason to believe that this is not the case throughout the entire mass of the earth, that each cubic foot, or yard, or mile is supported or in turn supports its neighboring equivalent along such lines. The theory is not a new one, and its field is too large to encompass within the limits of a single paper, but, for practical purposes, and within the limited areas to which we must necessarily be confined, the writer believes it can be established beyond controversy as true. Certain it is that no one has yet found, in ground free from water pressure or abnormal conditions, any evidence of greater pressure at the bottom of a deep shaft or tunnel than that near the surface. Pressures due to the widening of mines beyond the limits of safety must not be taken as a controversion of this statement, as all arches have limits of safety, more especially if the useless material below the theoretical intrados is only partly supported, or is allowed to be suspended from the natural arch.

The writer believes, also, that the question of confined foundations, in contradistinction to that of the spreading of foundations, may be worthy of full discussion, as it applies to safe and economical construction, and he offers, without special comment, the following observations:

He has found that, in soft ground, results are often obtained with small open caissons sunk to a depth of a few feet and cleaned out and filled with concrete, which offer much better resistance than spreading the foundation over four or five times the equivalent area.

He has found that small steel piles and coffer-dams, from 1-ft. cylinders to coffer-dams 4 or 5 ft. square, sunk to a depth of only 1 or 2 ft. below adjacent excavations in ordinary sand, have safely resisted loads four or five times as great as those usually allowed.

He believes that short cylinders, cleaned out and filled with concrete, or coffer-dams of short steel piling with the surface cleaned out to a reasonable depth and filled with concrete horizontally reinforced, will, in many instances, give as good results as, and, in most cases, very much better than, placing the foundation on an equivalent number of small long piles or a proportionately greater spread of foundation area, the idea being that the transmission of pressure to the sides of the coffer-dam will not only confine the side thrust, but will also transfer the loading in mass to a greater depth where the resistance to

lateral pressure in the ground will be more stable; that is, the greater depth of foundation is gained without the increased excessive loading, or necessity for deep excavation.

As to the question of the bearing value and friction on piles, the writer believes that while the literature on engineering is full of experimental data relating to friction on caissons, there is little to show the real value of friction on piles. The assumption generally made of an assumed bearing value, and the deduction therefrom of a value for the skin friction is fallacious. Distinction, also, is not made, but should be clearly drawn between skin friction, pure and simple, on smooth surfaces and the friction due to pressure. Too often the bearing value on irregular surfaces as well as the bearing due to taper in piles, and lastly the resistance offered by binding, enter into the determination of so-called skin friction formulas. The essential condition of sinking a caisson is keeping it plumb; and binding, which is another way of writing increased bearing value, will oftentimes be fatal to success.

The writer believes that a series of observations on caissons sunk plumb under homogeneous conditions of ground and superficial smoothness will show a proportional increase of skin friction per square foot average for each increase in the size of caissons, as well as for increase of depth in the sinking up to certain points, where it may finally become constant, as will be shown later. The determination of the actual friction or coefficient of friction between the surfaces of the pile and the material it encounters, is not difficult to determine. In sand it is approximately 40% of the pressure for reasonably smooth iron or steel, and 45% of the pressure for ordinary wood surfaces. If, for instance, a long shaft be withdrawn vertically from moulding sand, the hole may remain indefinitely as long as water does not get into it or it does not dry out. This is due to the tendency of the sand to arch itself horizontally over small areas. The same operation cannot be performed on dry sand, as the arching properties, while protecting the pile from excessive pressure due to excessive length, will not prevent the loose sand immediately surrounding the pile from exerting a constant pressure against the pile, and it is of this pressure that 45% may be taken as the real value of skin friction on piles in dry sand.

In soft clays or peats which are displaced by driving, the tendency of this material to flow back into the original space causes pressure, of

which the friction will be a measured percentage. In this case, however, the friction itself between the material and the clays or peat is usually very much less than 40%, and it is for this reason that piles of almost indefinite length may be driven in materials of this character without offering sufficient resistance to be depended on, as long as no good bearing ground is found at the point.

If this material is under water, and is so soft as to be considered semi-aqueous, the pressure per square foot will increase in diminishing proportion to the depth, and the pressure per area will soon approach and become a constant, due to the resistance offered by the lateral arching of the solid material; whereas, in large circular caissons, or caisson shafts, where the horizontal arching effect is virtually destroyed, or at least rendered non-effective until a great depth is reached, the pressure must necessarily vary under these conditions proportionately to the depth and size of the caisson in semi-aqueous material. On the other hand, in large caisson shafts, especially those which are square, the pressure at the top due to the solid material will also increase proportionately to the depth, as already explained in connection with the pressures of earth against sheeting and retaining walls.

The writer believes that the pressure on these surfaces may be determined with reasonable accuracy by the formulas already given in this paper, and with these pressures, multiplied by the coefficient of friction determined by the simplest experiment on the ground, results may be obtained which will closely approximate the actual friction on caissons at given depths. The friction on caissons, which is usually given at from 200 to 600 lb. per sq. ft., is frequently assumed to be the same on piles 12 in. or less in diameter, whereas the pressures on these surfaces, as shown, are in no way comparable.

The following notes and observations are given in connection with the skin friction and the bearing value of piles:

The writer has in his possession a copy of an official print which was recently furnished to bidders in connection with the foundation for a large public building in New York City. The experiments were made on good sand at a depth of approximately 43 ft. below water and 47 ft. below an adjacent excavation. In this instance a 16-in. pipe was sunk to the depth stated, cleaned out, and a 14-in. piston connected to a 10-in. pipe was inserted and the ground at the bottom of the 16-in. pipe subjected to a loading approximating 28 tons per sq. ft.

After an initial settlement of nearly 3 in., there was no further settlement over an extended period, although the load of 28 tons per sq. ft. was continued.

In connection with some recent underpinning work, 14-in. hollow cylindrical piles 6 ft. long were sunk to a depth of 6 ft. with an ordinary hand-hammer, being excavated as driven. These piles were then filled with concrete and subjected to a loading in some cases approximating 60 tons. After a settlement ranging from 9 to 13 in., no further settlement took place, although the loading was maintained for a considerable period.

In connection with some other pile work, the writer has seen a 10-in. pipe, $\frac{3}{8}$ in. thick, 4 ft. below the bottom of an open cylinder, at a depth of about 20 ft., sustain in gravel and sand a load approximating 50 tons when cleaned out to within 2 ft. of the bottom.

He has seen other cylindrical piles with a bearing ring of not more than $\frac{3}{4}$ in. resting on gravel at a depth of from 20 to 30 ft., cleaned out practically to the bottom, sustain a measured load of 60 tons without settlement.

As to skin friction in sand, a case came under his observation wherein a 14-in. hollow cylindrical pile which had stood for 28 days at a depth of about 30 ft. in the sand, was cleaned out to its bottom and subjected to hydraulic pressure, measured by a gauge, and sunk 2 ft. into the sand without any pressure being registered on the gauge. It should be explained, however, that the gauge could be subjected to a pressure of 250 lb., equal to a total pressure of 7 000 lb. on the piston of the jack without registering, which corresponded, assuming it all as skin friction, to a maximum of not more than 78 lb. per sq. ft., but it should be noted that this included bearing value as well, and that the pressure was very far from 7 000 lb. in all probability at the beginning of the test.

In the case of the California stove-pipe wells driven by the Board of Water Supply on Long Island, the writer is informed that one of these tubes, 12 in. in diameter, was sunk to a depth of 850 ft. In doing this work the pile was excavated below the footing with a sand pump and was then sunk by hydraulic pressure. Assuming the maximum capacity of the jacks at 100 tons, which is not probable, the skin friction could not have amounted to more than 75 lb. per sq. ft. It cannot be assumed in this case that the excavation of the material

below the pile relieved the skin itself of some of its friction, as the operation consumed more than 6 weeks, and, even if excess material was removed, it is certain that a large percentage of it would have had time to adjust itself before the operation was completed.

In connection with this, the writer may call attention to the fact that piles driven in silt along the North River, and in soft material at other places, are sometimes 90 ft. in length, and even then do not offer sufficient resistance to be depended on for loading. This is due to the fact that the end of the pile does not bear in good material.

The relation between bearing value and skin friction on a pile, where the end bearing is in good material, is well shown by a case where a wooden pile* struck solid material, was distorted under the continual blows of the hammer, and was afterward exposed. It is also shown in the case of a 14-in. California stove-pipe pile, No. 14 gauge, the point of which met firm material. The result, as shown by Fig. 1, Plate LXXXI, speaks for itself. Fig. 2, Plate LXXXI shows a Chenowith pile which was an experimental one driven by its designer. This pile, after getting into hard material, was subjected to the blow of a 4 000-lb. hammer falling the full length of the pile-driver, and the only result was to shatter the head of the pile, and not cause further penetration. Mr. Chenowith has stated to the writer that he has found material so compact that it could not be penetrated with a solid pile—either with or without jetting, which is in line with the writer's experience.

The writer believes that the foregoing notes will show conclusively that the factor to be sought in pile work is bearing value rather than depth or skin friction, and, however valuable skin friction may be in the larger caissons, it cannot be depended on in the case of small piles, except in values ranging from 25 to 100 lb. per sq. ft.

In conclusion, he desires to thank the following gentlemen, who have contributed to the success of the experiments noted herein: Mr. James W. Nelson, of Richard Dudgeon, New York; Mr. George Noble, of John Simmons and Company, New York; and Mr. Pendleton, of Hindley and Pendleton, Brooklyn, N. Y.; all of whom have furnished apparatus for the experiments and have taken an interest in the results. And lastly, he desires especially to thank Mr. F. L. Cranford, of the Cranford Company, for men and material with which to make

* *Engineering News*, January 15th, 1909.

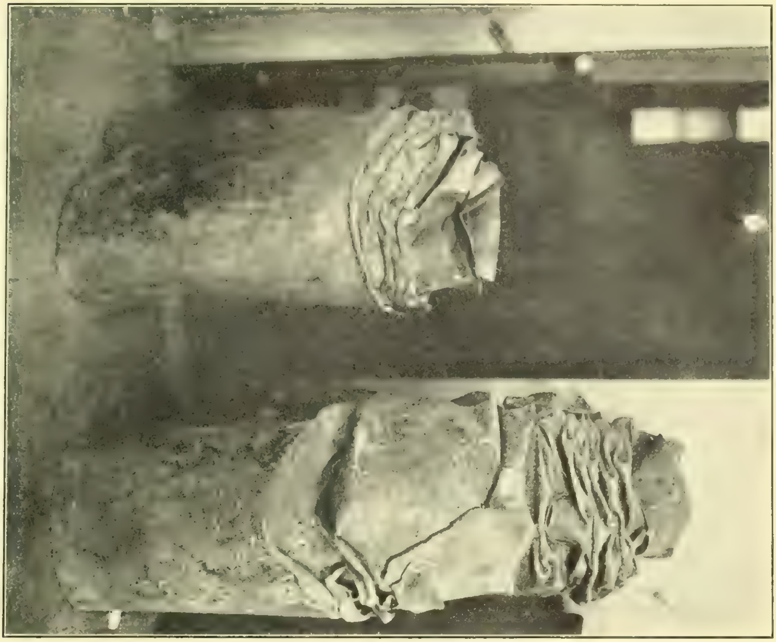


FIG. 1.—A 14 GAUGE 14-IN. HOLLOW (NON-TELESCOPIC) CALIFORNIA STOVE-PIPE PILE WHICH MET IMPENETRABLE MATERIAL.

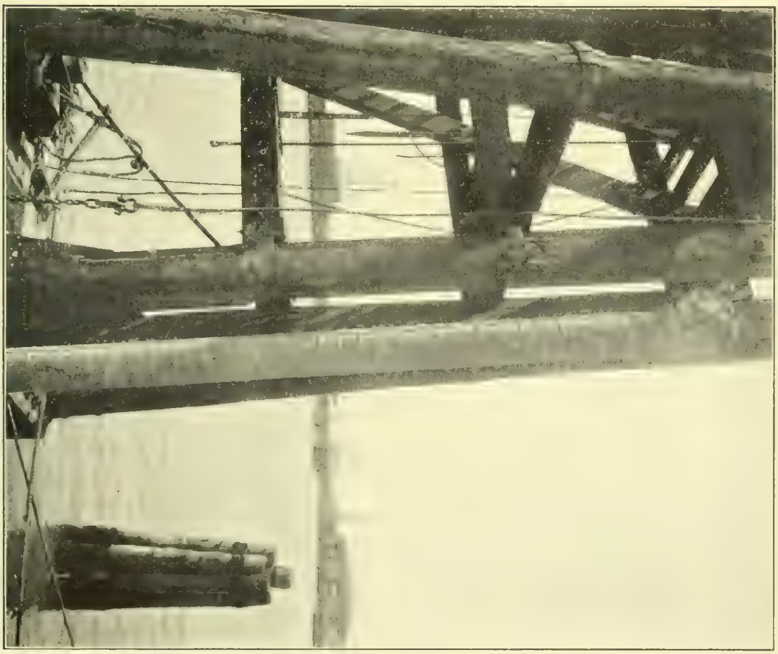


FIG. 2.—CHENOWITH PILE, PENETRATING HARD MATERIAL.

the experiments and without whose co-operation it would have been impracticable for the writer to have made them.

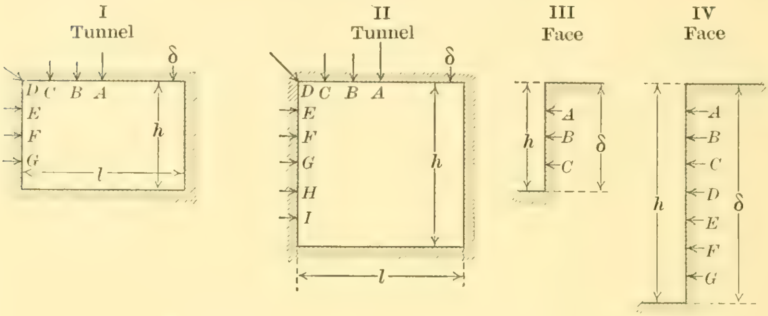
Throughout this paper the writer has endeavored, as far as possible, to deduce from his observations and from the observations of others, as far as he has been able to obtain them, practical data and formulas which may be of use in establishing the relationship between the pressure, resistance, and stability of earths; and, while he does not wish to dictate the character of the discussion, he does ask that those who have made observations of a similar character or who have available data, will, as far as possible, contribute the same to this discussion. It is only by such observations and experiments, and deductions therefrom, that engineers may obtain a better knowledge of the handling of such materials.

The writer believes that too much has been taken for granted in connection with earth pressures and resistance; and that, far too often, observations of the results of natural laws have been set down as phenomena. He believes that, both in experimenting and observing, the engineer will frequently find what is being looked for or expected and will fail to see the obvious alternative. He may add that his own experiments and observations may be criticized for the same reason, and he asks, therefore, that all possible light be thrown on this subject. A comparative study of much of our expert testimony or of the plans of almost any of the structures designed in connection with their bearing upon earth, or resistance to earth pressure, will show that under the present methods of interpretation of the underlying principles governing the calculations and designs relating to such structures, the results vary far too widely. Too much is left to the judgment of the engineer, and too frequently no fixed standards can be found for some of the most essential conditions.

Until the engineer can say with certainty that his calculations are reasonably based on facts, he is forced to admit that his design must be lacking, either in the elements of safety, on the one hand, or of economy, on the other, and, until he can give to his client a full measure of both these factors in fair proportion, he cannot justly claim that his profession has reached its full development.

Table 1 gives approximate calculations of pressures on two types of tunnels and on two heights of sheeted faces or walls, due to four widely varying classes of materials.

TABLE 1.—PRESSURES ON TYPICAL STRUCTURES UNDER VARYING ASSUMED CONDITIONS.



Key to Table of Pressures, etc.

h = exterior height, l = exterior width,

$\left\{ \begin{array}{l} \delta = \text{depth of cover, that is,} \\ D_E = \text{earth, and } D_W = \text{water depth,} \end{array} \right.$

ϕ = angle of repose, and, for tunnels $D_W > D_E >$ a depth

$$= \frac{l}{2} \left(45^\circ + \frac{\phi}{2}\right)$$

W_E = weight of 1 cu. ft. of earth = 90 lb.; W_W = weight of 1 cu. ft. of water = $62\frac{1}{2}$ lb.

Conditions: 1 = normal sand, 2 = dry sand, 3 = supersaturated firm sand with no voids, 4 = supersaturated semi-aqueous material, 60% aqueous, that is, 60% water and aqueous material.

Combined assumed conditions.	h	l	ϕ	D_E	Combined assumed conditions.	h	l	ϕ	D_E	D_W
I_1	20	30	45°	40	I_3	20	30	50°	40	60
I_2	20	30	30°	40	I_4	20	30	40°	40	60
II_1	15	15	45°	40	II_3	15	15	50°	40	60
II_2	15	15	30°	40	II_4	15	15	40°	40	60
III_1	15	....	45°	15	III_3	15	....	50°	15	15
III_2	15	....	30°	15	III_4	15	....	40°	15	15
IV_1	30	....	45°	30	IV_3	30	....	50°	30	30
IV_2	30	....	30°	30	IV_4	30	....	40°	30	30

TABLE 1.—(*Continued.*)

APPROXIMATE PRESSURES ON TUNNEL, PER SQUARE FOOT.

Pressure, per square foot, at	I_1 Earth.	I_3 Earth.	I_3 Water.	I_3 Combined.	I_2 Earth.	I_4 Earth.	I_4 Water.	I_4 Combined.	II_1 Earth.	II_3 Earth.	II_3 Water.	II_3 Combined.	II_2 Earth.	II_4 Earth.	II_4 Water.	II_4 Combined.
A	3 240	3 690	1 500	5 190	2 325	2 880	2 250	5 130	1 485	1 755	1 500	3 255	1 035	1 305	2 250	3 555
B	2 745	3 105	1 500	4 605	1 845	2 385	2 250	4 635	1 305	1 485	1 500	2 985	945	1 170	2 250	3 420
C	2 160	2 475	1 500	3 975	1 350	1 800	2 250	4 050	1 125	1 215	1 500	2 715	810	990	2 250	3 240
D	450	540	1 500	2 040	450	450	2 250	2 700	405	405	1 500	1 905	540	450	2 250	2 700
E	360	360	1 625	1 985	450	450	2 438	2 888	405	405	1 625	2 030	540	450	2 438	2 888
F	270	270	1 750	2 025	450	360	2 626	2 986	360	360	1 750	2 110	540	450	2 626	3 076
G	225	225	1 875	2 100	360	270	2 814	3 084	315	315	1 875	2 190	360	360	2 814	3 174
H	....	....	....	....	....	....	....	....	180	225	2 000	2 225	180	180	3 000	3 180
I	....	....	....	....	....	....	....	....	90	110	2 175	2 285	135	135	3 188	3 323

APPROXIMATE PRESSURES ON SHEETED TRENCH FACES OR WALLS.

Pressure per square foot at	III_1 Earth.	III_3 Earth.	III_3 Water.	III_3 Total earth and water.	III_2 Earth.	III_4 Earth.	III_4 Water.	III_4 Total earth and water.	IV_1 Earth.	IV_3 Earth.	IV_3 Water.	IV_3 Total earth and water.	IV_2 Earth.	IV_4 Earth.	IV_4 Water.	IV_4 Total earth and water.
A........	575	510	100	610	1 350	810	140	950	1 370	1 210	100	1 310	3 175	1 910	150	2 060
B........	400	350	190	540	900	540	260	800	1 170	1 030	200	1 230	2 700	1 610	290	1 900
C........	200	175	280	455	450	270	380	650	970	855	290	1 145	2 250	1 355	430	1 785
D........	....	....	....	....	....	....	....	....	775	680	370	1 050	1 800	1 100	570	1 670
E........	....	....	....	....	....	....	....	....	590	515	460	975	1 350	820	710	1 530
F........	....	....	....	....	....	....	....	....	400	350	560	910	900	540	860	1 400
G........	....	....	....	....	....	....	....	....	190	170	650	820	450	275	1 000	1 275

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PAPERS AND DISCUSSIONS

NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE NORTH RIVER TUNNELS.

By B. H. M. Hewett and W. L. Brown, Members, Am. Soc. C. E.

To be Presented June 1st, 1910.

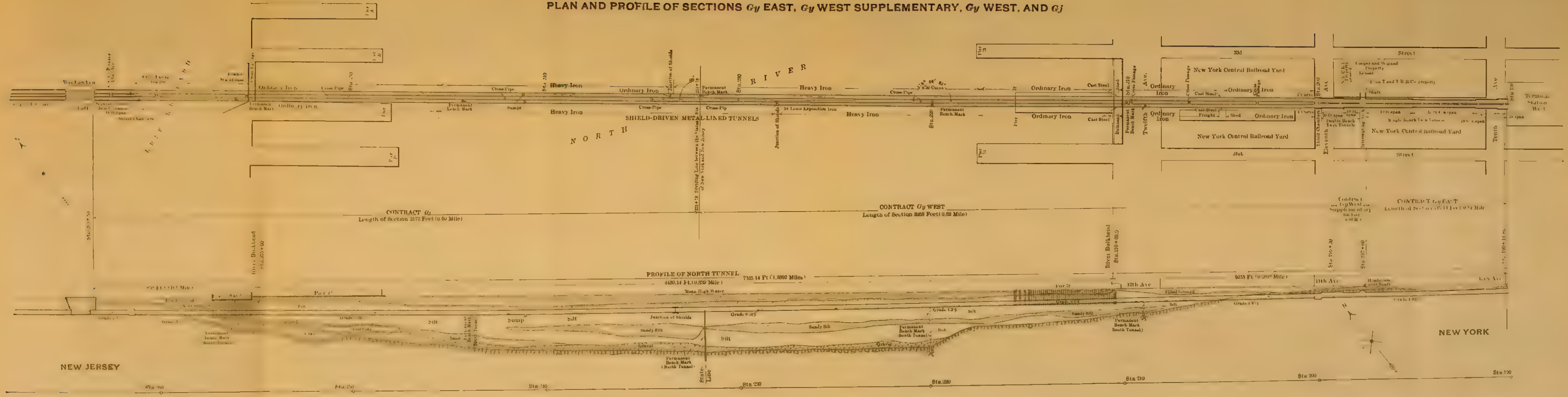
Introduction.

The section of the Pennsylvania Railroad Tunnel work described in this paper is that lying between Tenth Avenue, New York City, and the large shaft built by the Company at Weehawken, N. J., and thus comprises the crossing of the North or Hudson River, the barrier which has stood for such a long time between the railroads and their possession of terminal stations in New York City. The general plan and section, Plate LXXXII, shows the work included.

This paper is written from the point of view of those engaged by the Chief Engineer of the Railroad Company to look after the work of construction in the field. The history of the undertaking is not included, the various phases through which many of the designs and plans passed are not followed, nor are the considerations regarding foundations under the subaqueous portions of the tunnels and the various tests made in connection with this subject set out, as all these matters will be found in other papers on these tunnels.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

PLAN AND PROFILE OF SECTIONS *Gy* EAST, *Gy* WEST SUPPLEMENTARY, *Gy* WEST, AND *Gj*



This paper only aims to describe, as briefly as possible, the actual designs which were finally adopted, the actual conditions met on the ground, and the methods of construction adopted by the contractors.

For easy reference, and to keep the descriptions of work of a similar character together, the subject will be treated under the four main headings, viz.: Shafts, Plant, Land Tunnels, and River Tunnels.

Shafts.

It is not intended to give much length to the description of the Shafts or the Land Tunnels, as more interest will probably center in the River Tunnels.

The shafts did not form part of the regular tunnel contract, but were built under contract by the United Engineering and Contracting Company while the contract plans for the tunnel were being prepared. In this way, when the tunnel contracts were let, the contractor found the shafts ready, and he could get at his work at once.

Two shafts were provided, one on the New York side and one on the New Jersey side. Their exact situation is seen on Plate LXXXII. They were placed as near as possible to the point at which the disappearance of the rock from the tunnels made it necessary to start the shield-driven portion of the work.

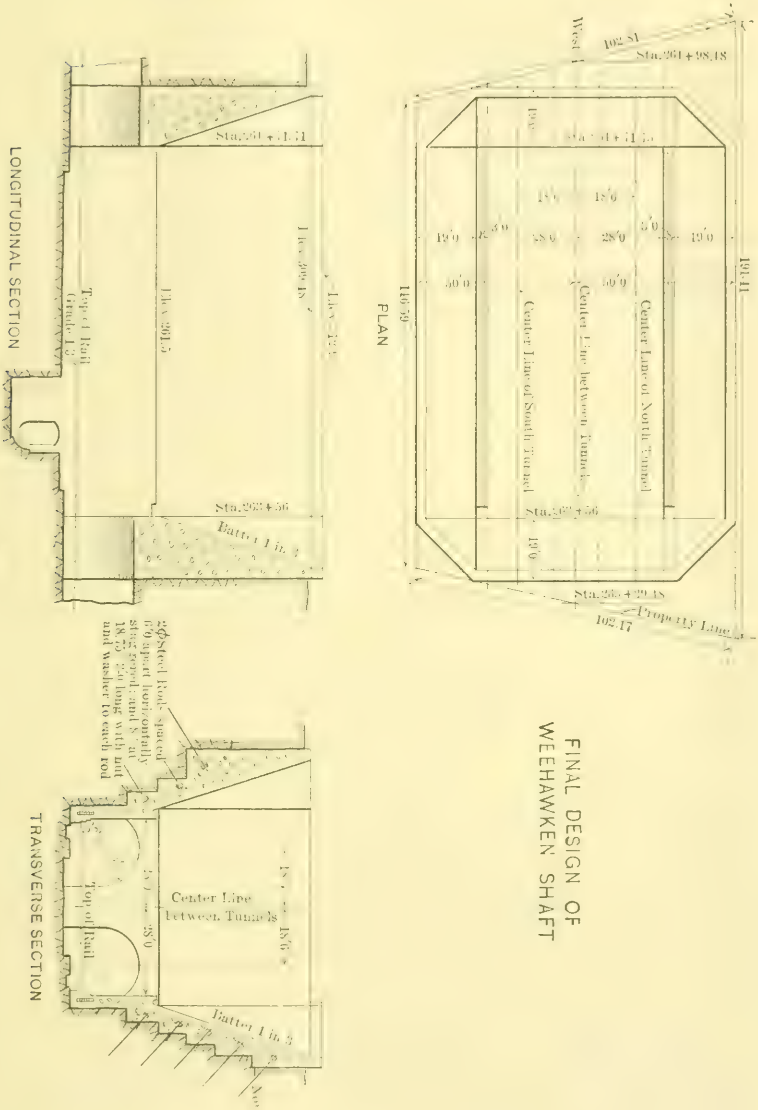
The details of the shafts will now be described briefly.

The Manhattan Shaft.—The Manhattan Shaft is located about 100 ft. north of the tunnel center; there was nothing noticeable about its construction. General figures relating to both shafts are given in Table 1.

The Weehawken Shaft.—The Weehawken Shaft is shown in Fig. 1. This, as will be seen from Table 1, was a comparatively large piece of work. The shaft is over the tunnels, and included both of them. In the original design the wall of the shaft was intended to follow in plan the property line shown in Fig. 2, and merely to extend down to the surface of the rock, which, as disclosed by the preliminary borings, was here about 15 ft. below the surface. However, as the excavation proceeded, it was found that this plan would not do, as the depth to the rock surface varied greatly, and was often much lower than expected; the rock itself, moreover, was very treacherous, the cause being that the line of junction between the triassic sandstone, which is here the country rock, and the intrusive trap of the Bergen Hill ridge.

TABLE 1.—PARTICULARS OF SHAFTS ON THE NORTH RIVER TUNNELS OF THE PENNSYLVANIA RAILROAD TUNNELS INTO NEW YORK CITY.

Location.	Depth, in feet.	Width, in feet.	Length, in feet.	Excavation (including drifts), in cubic yards.	Concrete, in cubic yards.	Date commenced.	Date finished.	Ground met:	Lined with:	Cost to Railroad Company.	Cost per cubic foot.
Manhattan: 11th Avenue and 32d Street......	55	22	32	2 010	209	June 10th, 1903.	December 11th, 1903.	Top 13 ft. filled; red mica schist and granite.	Concrete reinforced with steel beams down to rock.	$12 943.75	$0.335
Weehawken: Baldwin Avenue.	76	At bottom 56, at top 100.	At bottom 115.75, at top 154.	55 315	9 810	June 11th, 1903.	September 1st, 1904.	Top 6 ft., 30 ft. sand and hard-pan, decomposed rock (trap and sandstone) below.	Concrete with steel tie-rods in rock.	166 162.93	0.337



FINAL DESIGN OF WEEHAWKEN SHAFT

FIG. 1

occurs about one-third of the length of the shaft from its western end, causing more or less disintegration of both kinds of rock. Therefore it was decided to line the shaft with concrete throughout its entire depth, the shape being changed to a rectangular plan, as shown in the drawings. At the same time that the shaft was excavated, a length of 40 ft. of tunnels at each end of it was taken out, also on account of the treacherous nature of the ground, thus avoiding risk of injury to the shaft when the tunnel contractors commenced work. There was much trouble with floods during the fall of 1903, and numerous heavy falls of ground occurred, in spite of extreme care and much heavy timbering. The greatest care was also taken in placing the concrete lining, and the framing to support the forms was carefully designed and of heavy construction; the forms were of first-class workmanship, and great care was taken to keep them true to line. A smooth surface was given to the concrete by placing a 3-in. layer of mortar at the front of the walls and tamping this dry facing mixture well down with the rest of the concrete. The east and west walls act as retaining walls, while those on the north and south are facing walls, and are tied to the rock with steel rods embedded and grouted into the rock and into the concrete. Ample drainage for water at the back of the wall was provided by upright, open-joint, vitrified drains at frequent intervals, with dry-laid stone drains leading to them from all wet spots in the ground. A general view of the finished work is shown in Fig. 1, Plate LXXXIII, and Table 1 gives the most important dates and figures relating to this shaft.

After the tunnel work was finished, both shafts were provided with stairs leading to the surface, a protective head-house was placed over the New York Shaft, and a reinforced concrete fence, 8 ft. high, was built around the Weehawken Shaft on the Company's property line, that is, following the outline of the shaft as originally designed.

Plant.

Working Sites.

Before beginning a description of the tunnel work, it may be well to set out in some detail the arrangements made on the surface for conducting the work underground.

All the work was carried on from two shafts, one at Eleventh Avenue and 32d Street, New York City—called the Manhattan Shaft

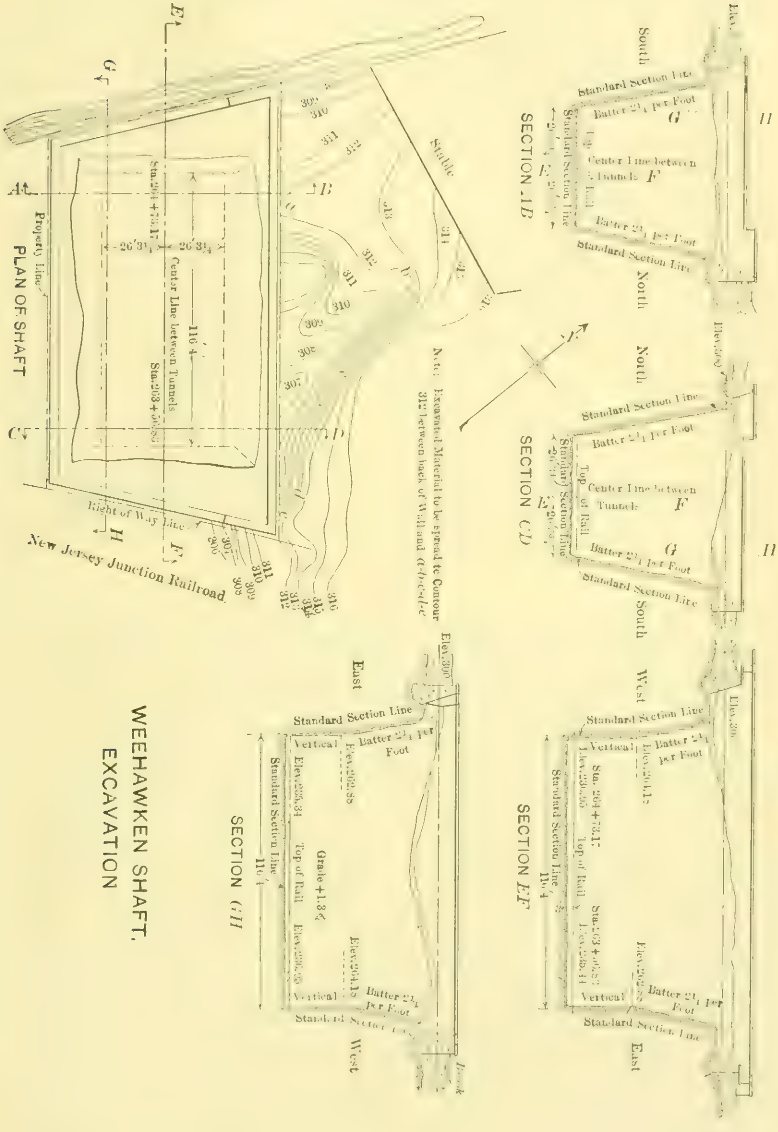

WEEHAWKEN SHAFT,
EXCAVATION
PLAN OF SHAFT
SECTION AB
SECTION CD
SECTION EF
SECTION GH
Center Line between Tunnels
Sta. 263+56.83
Sta. 264+73.17
Property Line
Right of Way Line
New Jersey Junction Railroad
Stable
Note: Excavated Material to be spread to Contour 312 between back of Wall and a-b-c-d-e
Standard Section Line
Batter 2¼ Per Foot
Top of Rail
Grade +1.34
North
South
East
West

Fig. 2.

—and one at Baldwin Avenue, Weehawken, N. J.—called the Weehawken Shaft.

The characteristics of the two sites were radically different, and called for different methods of handling the transportation problem. The shaft site at Manhattan is shown on Plate LXXXIV. It will be seen that there was not much room, in fact, the site was too cramped for comfort; the total area, including the space occupied by the old foundry, used for power-houses, offices, etc., was about 3 250 sq. yd. This made it necessary to have two stages, one on the ground level for handling materials into the yard, and an overhead gantry on which the excavated materials were handled off the premises. The yard at Weehawken was much larger; it is also shown on Plate LXXXIV. Its area was about 15 400 sq. yd. in the yard proper, and there was an additional space of about 750 sq. yd. alongside the wharf at the "North Slip," on the river front, connected with the main portion of the yard by an overhead trestle.

All the cars at Manhattan were moved by hand, but at Weehawken two electric locomotives with overhead transmission were used.

Power-House Plant.

At the Manhattan Shaft the power-house plant was installed on the ground floor of the old foundry building which occupied the north side of the leased area. This was a brick building, quite old, and in rather a tumble-down condition when the Company took possession, and in consequence it required quite a good deal of repair and strengthening work. The first floor of the building was used by the contractor as offices, men's quarters, doctor's offices, and so on, and on the next one above, which was the top floor, were the offices occupied by the Railroad Company's field engineering staff.

On the Weehawken side, the plant was housed in a wooden-frame, single-story structure, covered with corrugated iron. It was rectangular in plan, measuring 80 by 130 ft.

At both sides of the river the engines were bedded on solid concrete on a rock foundation.

The installation of the plant on the Manhattan side occupied from May, 1904, to April, 1905, and on the Weehawken side from September, 1904, to April, 1905. Air pressure was on the tunnels at the New York side on June 25th, 1905, and on the Weehawken side on the 29th of the same month.


SH121–Weehawken Shaft–Looking West
from Top. Aug 19, 1904

FIG. 1.


A 8 N.R.D. Section Gy West. North Tube Tunnel Manhattan
Face View of Shield during Construction Looking East
March 29. 1906.

FIG. 2.

The plants contained in the two power-houses were almost identical, there being only slight differences in the details of arrangement due to local conditions. A list of the main items of the plant at one power-house is shown in Table 2.

TABLE 2.—PLANT AT ONE POWER-HOUSE.

No. of items.	Description of item.	Cost.
Three	500-h.p. water-tube Sterling boilers	$15 186
Two	Feed pumps, George F. Blake Manufacturing Company	740
One	Henry R. Worthington surface condenser	6 539
Two	Electrically-driven circulating pumps on river front	5 961
Three	Low-pressure compressors, Ingersoll-Sergeant Drill Company	33 780
One	High-pressure compressor, Ingersoll-Sergeant Drill Company	6 665
Three	Hydraulic power pumps, George F. Blake Manufacturing Company	3 075
Two	General Electric Company's generators coupled to Ball and Wood engines	7 626
	Total cost of main items of plant	$79 572

SUMMARY OF COST OF ONE PLANT.

Total cost of main items of plant	$79 572
Cost of four shields (including installation, demolition, large additions and renewals, piping, pumps, etc.)	103 560
Cost of piping, connections, drills, derricks, installation of offices and all miscellaneous plant	101 818
Cost of installation, including preparation of site	39 534
Total prime cost of one power-house plant	$324 484

The following is a short description of each item of plant in Table 2:

Boilers.—At each shaft there were three 500-h.p., water-tube boilers, Class F, by Sterling and Company, Chicago, Ill. They had independent steel stacks, 54 in. in diameter and 100 ft. above grate level; each had 5 000 sq. ft. of heating surface and 116 sq. ft. of grate area. The firing was by hand, and there were shaking grates and four doors to each furnace. Under normal conditions of work, two boilers at each plant were able to supply all the steam required. The average working pressure of the steam was 135 lb. per sq. in.

The steam piping system was on the loop or by-pass plan. The diameter of the pipes varied from 14 in. in the main header to 10 in. in the body of the loop. The diameter of the exhaust steam main increased from 8 in. at the remote machines to 20 in., and then to 30 in., at the steam separator, which in turn was connected with the condensers. A pipe with an automatic relief valve from the exhaust

to the atmosphere was used when the condensers were shut down. All piping was of the standard, flanged, extra-heavy type, with bronze-seated gate-valves on the principal lines, and globe-valves on some of the auxiliary ones. There was an 8-in. water leg on the main header fitted with a Mason-Kelly trap, and other smaller water traps were set at suitable intervals.

Each boiler was fitted with safety valves, and there were automatic release valves on the high- and low-pressure cylinders of each compressor, as well as on each air receiver.

Buckwheat coal was used, and was delivered to the bins on the Manhattan side by teams and on the Weehawken side by railroad cars or in barges, whence it was taken to the power-house by 2-ft. gauge cars. An average of 20 tons of coal in each 24 hours was used by each plant.

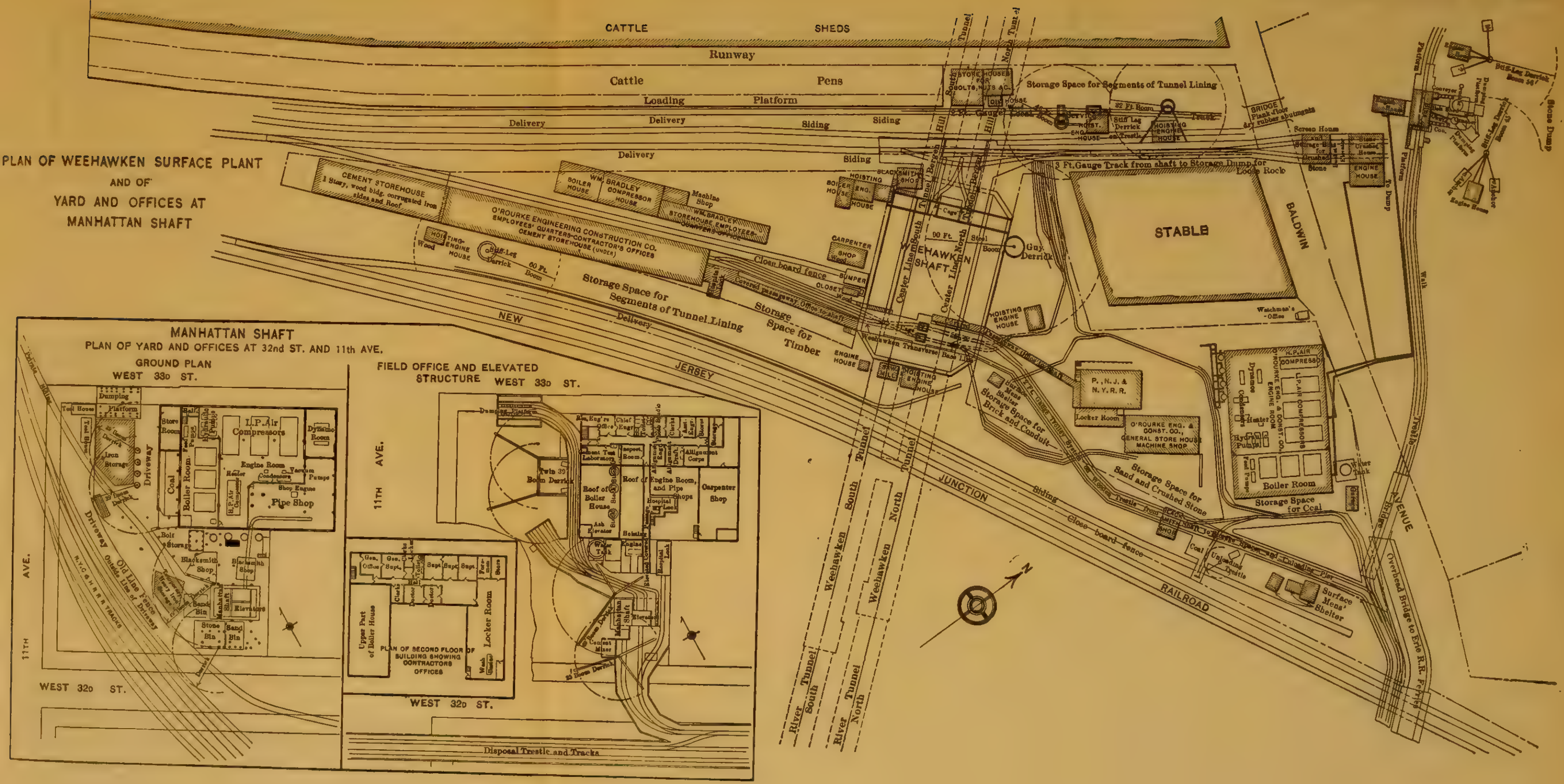
The water was taken directly from the public service supply main. The daily quantity used was approximately 4 000 gal. for boiler purposes and 4 400 gal. for general plant use. Wooden overhead tanks having a capacity of 14 000 gal. at each plant served as a 12-hour emergency supply.

Feed Pumps.—There were two feed pumps at each plant. They had a capacity of 700 cu. ft. per min., free discharge. The plungers were double, of 6-in. diameter, and 10-in. stroke, the steam cylinders were of 10-in. diameter and 10-in. stroke. An injector of the "Metropolitan Double-Tube" type, with a capacity of 700 cu. ft. per min., was fitted to each boiler for use in emergencies.

The feed-water heater was a "No. 9 Cochrane," guaranteed to heat 45 000 lb. of water per hour, and had a total capacity of 85.7 cu. ft. It was heated by the exhaust steam from the non-condensing auxiliary plant.

Condenser Plant.—There were two surface condensers at each plant. Each had a cooling surface sufficient to condense 22 500 lb. of steam per hour, with water at a temperature of 70° Fahr. and barometer at 30 in., maintaining a vacuum of 26 in. in the condenser. Each was fitted with a Blake, horizontal, direct-acting, vacuum pump.

Circulating-Water Pumps.—Two circulating-water pumps, supplying salt water directly from the Hudson River, were placed on the wharf. They were 8-in. centrifugal pumps, each driven by a 36-h.p., General Electric Company's direct-current motor (220 volts and 610


PLAN OF WEEHAWKEN SURFACE PLANT
AND OF
YARD AND OFFICES AT
MANHATTAN SHAFT
CATTLE
SHEDS
Runway
Cattle
Pens
Loading
Platform
Delivery
Siding
CEMENT STOREHOUSE
O'ROURKE ENGINEERING CONSTRUCTION CO.
Storage Space for Segments of Tunnel Lining
Storage Space for Timber
STABLE
BALDWIN
AVENUE
WEEHAWKEN SHAFT
NEW
JERSEY
JUNCTION
RAILROAD
Storage Space for Sand and Crushed Stone
Storage Space for Coal
Boiler Room
Weehawken South River Tunnel
Weehawken North River Tunnel
Overhead Bridge to Erie R.R. Ferries
MANHATTAN SHAFT
PLAN OF YARD AND OFFICES AT 32nd ST. AND 11th AVE.
GROUND PLAN
WEST 33D ST.
WEST 32D ST.
11TH AVE.
FIELD OFFICE AND ELEVATED STRUCTURE
L.P. Air Compressors
Engine Room
Pipe Shop
Blacksmith Shop
Locker Room
PLAN OF SECOND FLOOR OF BUILDING SHOWING CONTRACTORS OFFICES
Carpenter Shop
Disposal Trestle and Tracks

rev. per min.), the current being supplied from the contractor's power-house generators. The pumps were run alternately 24 hours each at a time. Those on the Manhattan side were 1 300 ft. from the power-house, and delivered their water through a 16-in. pipe; those on the Weehawken side were 450 ft. away, and delivered through a 14-in. pipe. There was also a direct connection with the city mains, in case of an accident to the salt-water pumps.

Low-Pressure Compressors.—At each plant there were three low-pressure compressors. These were for the supply of compressed air to the working chambers of the subaqueous shield-driven tunnels. They were also used on occasions to supply compressed air to the cylinders of the high-pressure compressors, thus largely increasing the capacity of the latter when hard pressed by an unusual call on account of heavy drilling work in the rock tunnels. They were of a new design, of duplex Corliss type, having cross-compound steam cylinders, designed to operate condensing, but capable of working non-condensing; the air cylinders were simple duplex. The steam cylinder valves were of the Corliss release type, with vacuum dash-pots. The valves in the air cylinders were mechanically-operated piston valves, with end inlet and discharge. The engines used steam at 135 lb. pressure. The high- and low-pressure steam cylinders were 14 in. and 30 in. in diameter, respectively, with a stroke of 36 in. and a maximum speed of 135 rev. per min. The two air cylinders were 23½ in. in diameter, and had a combined capacity of 35.1 cu. ft. of free air per revolution, and, when running at 125 rev. per min., each machine had an actual capacity of 4 389 cu. ft. of free air per min., or 263 340 cu. ft. per hour. The air cylinders were covered by water-jackets through which salt water from the circulating pumps flowed. A gauge pressure of 50 lb. of air could be obtained.

Each compressor was fitted with an automatic speed and air-pressure regulator, designed to vary the cut-off according to the volume of air required, and was provided with an after-cooler fitted with tinned-brass tube and eight Tobin-bronze tube-plates having 809 sq. ft. of cooling surface; each one was capable of reducing the temperature of the air delivered by it to within 10° Fahr. of the temperature of the cooling water when its compressor was operated at its fullest capacity. From the after-cooler the air passed into a vertical receiver, 4 ft. 6 in. in diameter and 12 ft. high, there being

one such receiver for each compressor. The receivers were tested to a pressure of 100 lb. per sq. in. The after-coolers were provided with traps to collect precipitated moisture and oil. The coolers and receivers were fitted with safety valves set to blow off at 1 lb. above the working pressure. The air supply was taken from without, and above the power-house roof, but in very cold weather it could be taken from within doors.

High-Pressure Compressors.—There was one high-pressure compressor at each plant. Each consisted of two duplex air cylinders fitted to a cross-compound, Corliss-Bass, steam engine. The two steam cylinders were 14 and 26 in. in diameter, respectively, and the air cylinders were 14¼ in. in diameter and had a 36-in. stroke. The air cylinder was water-jacketed with salt water supplied from the circulating water pumps.

The capacity was about 1 100 cu. ft. of free air per min. when running at 85 rev. per min. and using intake air at normal pressure, but, when receiving air from the low-pressure compressors at a pressure of 30 lb. per sq. in., the capacity was 3 305 cu. ft. of free air per min.; receiving air at 50 lb. per sq. in., the capacity would have been 4 847 cu. ft. of free air per min. This latter arrangement, however, called for more air than the low-pressure compressors could deliver. With the low-pressure compressor running at 125 rev. per min. (its maximum speed), it could furnish enough air at 43.8 lb. per sq. in. to supply the high-pressure compressor running at 85 rev. per min. (its maximum speed); and, with the high-pressure compressor delivering compressed air at 150 lb., the combined capacity of the arrangement would have been 4 389 cu. ft. of free air per min.

The air passed through a receiver, 4 ft. 6 in. in diameter and 12 ft. high, tested under a water pressure of 225 lb. per sq. in., before being sent through the distributing pipes.

Hydraulic Power Pumps.—At each power-house there were three hydraulic power pumps to operate the tunneling shields. One pump was used for each tunnel, leaving the third as a stand-by. The duplex steam cylinders were 15 in. in diameter with a 10-in. stroke; the duplex water rams were 2½ in. in diameter with a 10-in. stroke. The pumps were designed to work up to 6 000 lb. per sq. in., but the usual working pressure was about 4 500 lb. The piping, which was extra heavy hydraulic, was connected by heavy cast-steel screw coup-

lings, having a hexagonal cross-section in the middle to enable tightening to be done with a bolt wrench. The piping was designed to withstand a pressure of 5 500 lb. per sq. in.

Electric Generators.—At each plant there were two electric generators supplying direct current for both lighting and power, at 240 volts, through a two-wire system of mains. They were of Type M-P, Class 6, 100 kw., 400 amperes, 250 rev. per min., 240 volts no load and 250 volts full load. They were connected direct to 10 by 20 by 14-in., center-crank, tandem-compound, engines of 150 h.p. at 250 rev. per min. A switch-board, with all the necessary fuses, switches, and meters, was provided at each plant.

Lubrication.—In the lubricating system three distinct systems were used, each requiring its own special grade of oil.

The journals and bearings were lubricated with ordinary engine oil by a gravity system; the oil after use passed through a "White Star" filter, and was pumped into a tank about 15 ft. above the engine-room floor.

The low-pressure air cylinders were lubricated with "High Test" oil, having a flash point of 600° Fahr. The oil was forced from a receiving tank into an elevated tank by high-pressure air. When the tank was full the high-pressure air was turned off and the low-pressure air was turned on, in this way the air pressure in the oil tank equalled that in the air cylinder being lubricated, thus allowing a perfect gravity system to exist.

The steam cylinders and the high-pressure air cylinders were fed with oil from hand-fed automatic lubricators made by the Detroit Lubrication Company, Detroit, Mich.

"Steam Cylinder" oil was used for the steam cylinders and "High Test" oil (the same as used for the low-pressure air cylinders) for the high-pressure air cylinders. The air cylinder and steam cylinder lubricators were of the same kind, except that no condensers were necessary. The steam cylinder and engine oil was caught on drip pans, and, after being filtered, was used again as engine oil in the bearings. The oil from the air cylinders was not saved, nor was that from the steam cylinders caught at the separator.

Cost of Operating the Power-House Plants.—In order to give an idea of the general cost of running these plants, Tables 3 and 4 are given as typical of the force employed and the general supplies needed

for a 24-hour run of one plant. Table 3 gives a typical run during the period of driving the shields, and Table 4 is typical of the period of concrete construction. In the latter case the tunnels were under normal air pressure. Before the junction of the shields, both plants were running continuously; after the junction, but while the tunnels were still under compressed air, only one power-house plant was operated.

TABLE 3.—COST OF OPERATING ONE POWER-HOUSE FOR 24 HOURS DURING EXCAVATION AND METAL LINING.

No.	Labor.	Rate per day.	Amount.
6	Engineers	$3.00	$18.00
6	Firemen	2.50	15.00
2	Oilers	2.00	4.00
2	Laborers	2.00	4.00
4	Pumpmen	2.75	11.00
2	Electricians	3.50	7.00
1	Helper	3.00	3.00
Total per day			$62.00
Total for 30 days			$1 860.00

SUPPLIES.

Coal (14 tons per day)	$3.25	$45.50
Water	7.00	7.00
Oil (4 gal. per day)	0.50	2.00
Waste (4 lb. per day)	0.07	0.28
Other supplies	1.00	1.00
Total per day		$55.78
Total for 30 days		$1 673.00
Total cost of labor and supplies for 30 days		$3 533.00

Stone-Crusher Plant.—A short description of the stone-crusher plant will be given, as it played an important part in the economy of the concrete work. In order to provide crushed stone for the concrete, the contractor bought (from the contractor who built the Bergen Hill Tunnels) the pile of trap rock excavated from these tunnels, which had been dumped on the piece of waste ground to the north of Baldwin Avenue, Weehawken, N. J.

The general layout of the plant is shown on Plate LXXXIV. It consisted of a No. 6 and a No. 8 Austin crusher, driven by an Amex, single-cylinder, horizontal, steam engine of 120 h.p., and was capable of crushing about 225 cu. yd. of stone per 10-hour day. The crushers and conveyors were driven from a countershaft, in turn driven from the engine by an 18-in. belt.

TABLE 4.—Cost of Operating the One Plant for 24 Hours During Concrete Lining.

No.	Labor.	Rate per day.	Amount.
2	Engineers	$3.00	$6.00
2	Firemen	2.50	5.00
2	Pumpmen	3.00	6.00
1	Foreman Electrician	6.00	6.00
1	Electrician	3.00	3.00
1	Laborer	2.00	2.00
Total per day			$28.00
Total for 30 days			$840.00
Supplies.			
Coal (14 tons per day)		$3.15	$44.10
Oil (4 gal. per day)		0.50	2.00
Water		13.00	13.00
Other supplies		2.00	2.00
Total per day			$61.10
Total for 30 days			$1 833.00
Total cost of labor and supplies for 30 days			$2 673.00

The process of crushing was as follows: The stone from the pile was loaded by hand into scale-boxes which were lifted by two derricks into the chute above the No. 6 crusher. One derrick had a 34-ft. mast and a 56-ft. boom, and was worked by a Lidgerwood steam hoister; the other had a 23-ft. mast and a 45-ft. boom, and was worked by a "General Electric" hoist. All the stone passed first through the No. 6 crusher, after which it was lifted by a bucket conveyor to a screen, placed about 60 ft. higher than and above the stone bin. The screen was a steel chute pierced by 2½-in. circular holes, and was on a slope of about 45°; in order to prevent the screen from choking, it

was necessary to have two men continually scraping the stone over it with hoes. All the stone passing the screen was discharged into a bin below with a capacity of about 220 cu. yd. The stone not passing the screen passed down a diagonal chute to a No. 3 crusher, from which, after crushing, it was carried back by a second bucket conveyor to the bin, into which it was dumped without passing a screen. The No. 3 crusher was arranged so that it could, when necessary, receive stone direct from the stone pile. The cars in which the stone was removed could be run under the bin and filled by opening a sliding door in the bottom of the bin. A track was laid from the bin to connect with the contractor's surface railway in the Weehawken Shaft yard, and on this track the stone could be transported either to the Weehawken Shaft direct, for use on that side of the river, or to the wharf, where it could be dumped into scows for transportation to New York.

The cars used were 3-cu. yd. side-dump, with flap-doors, and were hauled by two steam Dinky locomotives.

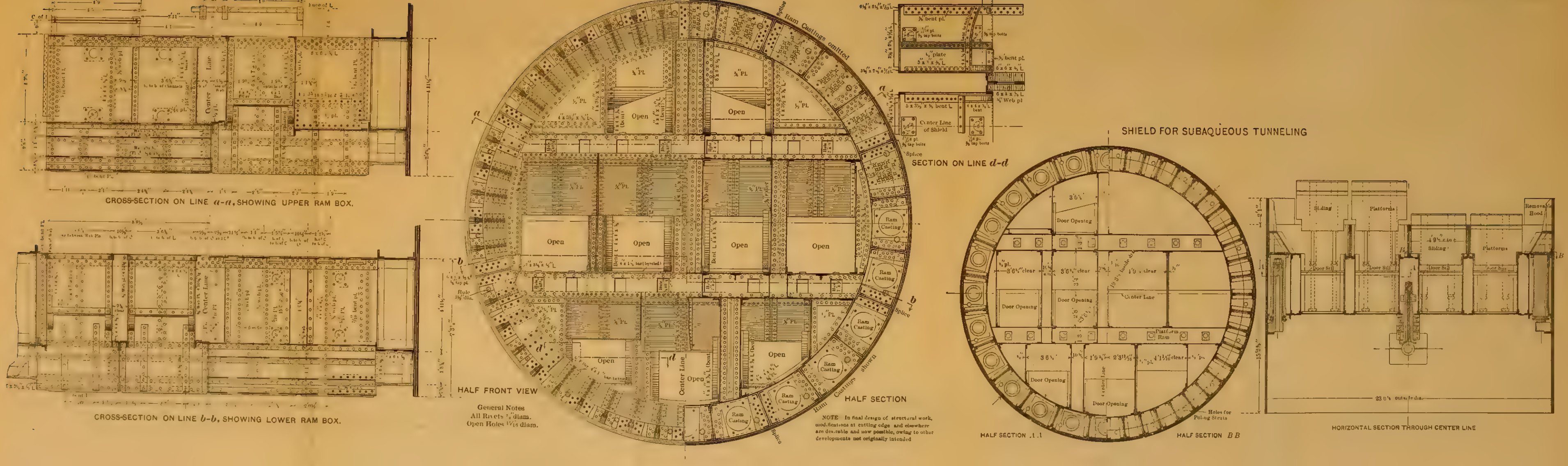
The average force employed was:

1 foreman	@	$3.00	per	day.	Supervising.
24 laborers	"	1.75	"	"	Loading scale-boxes for derricks.
4 laborers	"	1.75	"	"	Feeding crushers.
2 laborers	"	1.75	"	"	Watching screens to prevent clogging.
1 engineer	"	4.00	"	"	Driving steam engine.
2 engineers	"	3.50	"	"	On the derricks.
1 night watchman.					Watching the plant at night.

Owing to the constant break-down of machinery, chutes, etc., inseparable from stone-crushing work, there was always at work a repair gang consisting of either three carpenters or three machinists, according to the nature of the break-down.

The approximate cost of the plant was:

Machinery	$5 850
Lumber	3 305
Erection labor	3 999
Total	$13 154



CROSS-SECTION ON LINE a-a, SHOWING UPPER RAM BOX.

CROSS-SECTION ON LINE b-b, SHOWING LOWER RAM BOX.

The cost of the crushed stone at Weehawken amounted to about $0.91 per cu. yd., and was made up as follows:

Cost of stone	$0.22
Labor in operation of plant	0.31
Plant supplies	0.11
*Plant depreciation	0.27
Total	$0.91

The crushed stone at the Manhattan Shaft cost about $1.04 per cu. yd., the difference of $0.13 from the Weehawken cost being made up of the cost of transfer across the river, $0.08, and transport from the dock to the shaft, $0.05.

Miscellaneous Plant.—The various pieces of plant used directly in the construction work, such as derricks, hauling engines, pumps, concrete mixers, and forms, will be found described or at least mentioned in the description of the methods used in construction.

The tunneling shields, however, will be described now, as much of the description of the shield-driven work will not be clear unless preceded by a good idea of their design.

Tunneling Shields.

During the period in which the original contract drawings were being made, namely, in the latter part of 1903 and the early part of 1904, considerable attention was given to working out detailed studies for a type of shield which would be suitable for dealing with the various kinds of ground through which the shield-driven tunnels had to pass. This was done in order that, when the contract was let, the engineer's ideas of the requirements of the shields should be thoroughly crystallized, and so that the contractor might take advantage of this long-thought-out design, instead of being under the necessity of placing a hurried order for a piece of plant on which so much of the safety as well as of the speed of his work depended. Eventually, the contractor took over these designs as they stood, with certain minor modifications, and the shields as built and worked gave entire satisfaction. The chief points held in view were ample strength, easy access to the working face combined with ease and quickness of closing the

* Assuming that the scrap value of derricks and engines is one-half the cost, crushers one-third the cost, and other items nothing.

diaphragm, and general simplicity. A clear idea of the main features of the design can be gathered from Fig. 3 and Plate LXXXV.

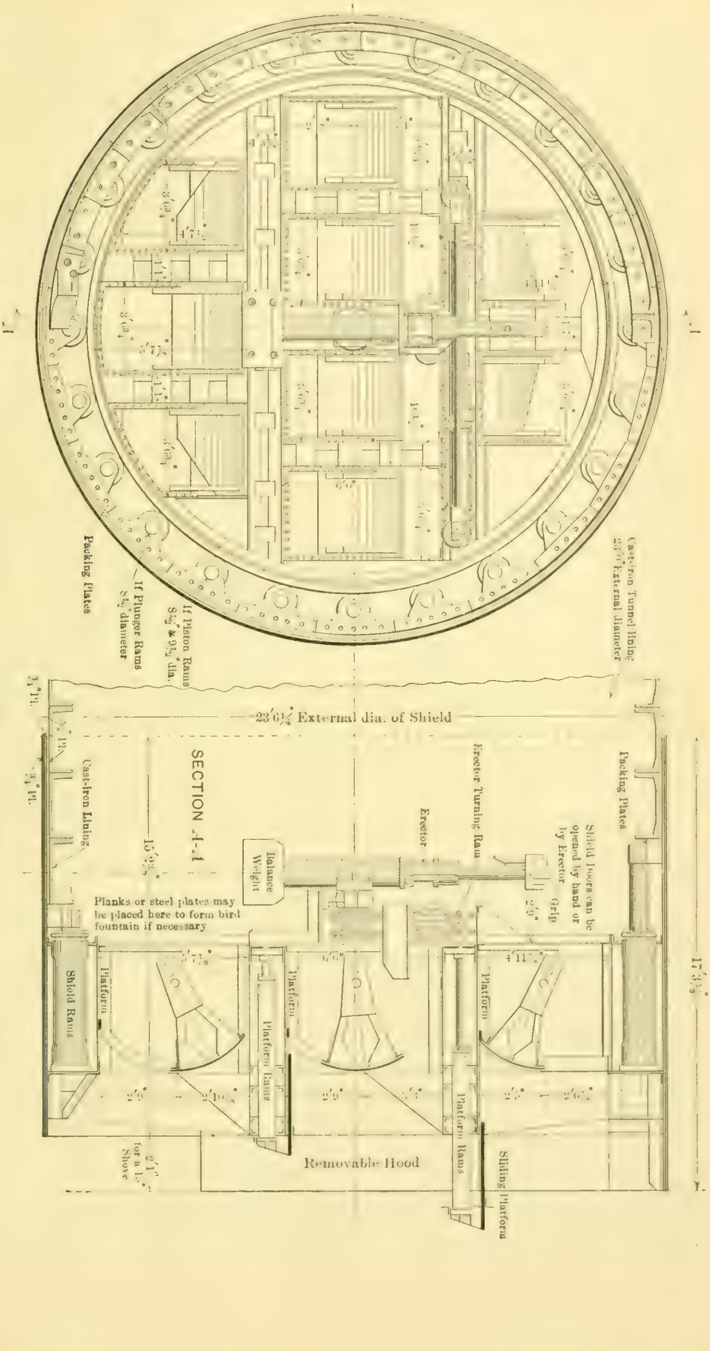
The interior diameter of the skin was 2 in. greater than the external diameter of the metal lining of the tunnel, which was 23 ft. The skin was made up of three thicknesses of steel plate, a $\frac{3}{4}$-in. plate outside and inside, with a $\frac{5}{8}$-in. plate between; thus the external diameter of the skin was 23 ft. $6\frac{1}{4}$ in. The length over all (exclusive of the hood, to be described later) was 15 ft. $11\frac{7}{16}$ in. The maximum overlap of the skin over the erected metal lining was 6 ft. $4\frac{1}{2}$ in., and the minimum overlap, 2 ft.

There were no inside or outside cover-plates, the joints of the various pieces of skin plates being butt-joints covered by the overlap of adjoining plates. All riveting was flush, both inside and outside. The whole circumference of each skin plate was made up of eight pieces, each of which extended the entire length of the shield, the only circumferential joint on the outside being at the junction of the removable cutting edge (or of the hood when the latter was in position) with the shield proper.

Forward of the back ends of the jacks, the shield was stiffened by an annular girder supporting the skin, and in the space between the stiffeners of which were set the 24 propelling rams used to shove the shield ahead by pressure exerted on the last erected ring of metal lining, as shown on Plate LXXXV.

To assist in taking the thrust of these rams, gusset-plates were placed against the end of each ram cylinder, and were carried forward to form level brackets supporting the cast-steel cutting edge segments. The stiffening gussets, between which were placed the rams, were also carried forward as level brackets for the same purpose. The cast-steel segmental cutting edge was attached to the front of the last mentioned plates.

The interior structural framing consisted of two floors and three vertical partitions, giving nine openings or pockets for access to the face; these pockets were 2 ft. 7 in. wide, the height varying from 2 ft. 2 in. to 3 ft. 4 in., according to their location. The openings were provided with pivoted segmental doors, which were adopted because they could be shut without having to displace any ground which might be flowing into the tunnel, and while open their own weight tended to close them, being held from doing so by a simple catch.



BACK VIEW OF SHIELD

PROPOSED SHIELD FOR SUBAQUEOUS TUNNELING
GENERAL ELEVATION

FIG. 3.

For passing through the varied assortment of ground before entering on the true sub-river silt, it was decided to adopt the forward detachable extension, or hood, which has so often proved its worth in ground needing timber for its support, as shown in Fig. 2, Plate LXXXIII. This hood extended 2 ft. 1 in. beyond the cutting edge, and from the top down to the level of the upper platform. Additional pieces were provided by which the hood might have been brought down as far as the lower platform, but they were not used. Special trapezoidal steel castings formed the junction between the hood and the cutting edge. The hood was in nine sections, built up of two $\frac{3}{4}$-in. and one $\frac{5}{8}$-in. skin plates, as in the main body of the skin, and was supported by bracket plates attached to the forward ends of the ram chambers. The hoods were bolted in place, and were removed and replaced by regular cutting-edge steel castings after the shields had passed the river lines.

The floors of the two platforms, of which there were eight, formed by the division of the platforms by the upright framing, could be extended forward 2 ft. 9 in. in front of the cutting edge, or 8 in. in front of the hood. This motion was given by hydraulic jacks. The sliding platform could hold a load of 7 900 lb. per sq. ft., which was equal to the maximum head of ground and water combined. The uses of these platforms will be described under the heading "Construction." The weight of the structural portion of each shield was about 135 tons.

The remainder of the shield was the hydraulic part, which provided its motive force and gave the power to the segment erector. The hydraulic fittings weighed about 58 tons per shield, so that the total weight of each shield was about 193 tons. The hydraulic apparatus was designed for a maximum pressure of 5 000 lb. per sq. in., a minimum pressure of 2 000 lb., and a test pressure of 6 000 lb. The actual average pressure used was about 3 500 lb. per sq. in.

There were 24 shoving rams, with a diameter of $8\frac{1}{2}$ in. and stroke of 38 in. The main ram was single-acting. The packings could be tightened up from the outside without removing the ram, a thing which is of the greatest convenience, and cannot be done with the differential plunger type. Some of the chief figures relating to the shield rams, with a water pressure of 5 000 lb. per sq. in., are:

Forward force of one ram.........	275 000 lb.
Forward force of 24 rams (all)....	6 600 000 "
Forward force of 24 rams.........	3 300 tons of 2 000 lb.
Equivalent pressure per square inch of face.................	105 lb.
Equivalent pressure per square foot of face.................	15 200 "
Pull-back force of one ram........	26 400 "
Pull-back pressure on full area of ram......................	480 " per sq. in.

The rams developed a tendency to bend, under the severe test of shoving the shield all closed, or nearly so, through the river silt, and it is probable that it would have been better to make the pistons 10 in. in diameter instead of 8½ in.

Each sliding platform was actuated by two single-acting rams, 3½ in. in diameter and having a stroke of 2 ft. 9 in. The rams were attached to the rear face of the shield diaphragm inside the box floors, and the cylinders were movable, sliding freely on bearings in the floor. The front ends of the cylinders were fixed to the front ends of the sliding platforms. The cylinder thus supported the front end of the sliding platform, and was designed to carry its half of the load on the platform. Some of the leading figures in connection with the platform rams, at a working pressure of 5 000 lb. per sq. in., are:

Forward force of each pair of rams (in each platform)............................	96 000 lb.
Total area of nose of sliding platform......	1 060 sq. in.
Maximum reaction per square inch on nose..	90 lb.
Maximum reaction per square foot on nose..	13 040 "

Each shield was fitted with a single erector mounted on the rear of the diaphragm. The erector consisted of a box-shaped frame mounted on a central shaft revolving on bearings attached to the shield. Inside of this frame there was a differential hydraulic plunger, 4 in. and 3 in. in diameter and of 48-in. stroke. To the plunger head were attached two channels sliding inside the box frame, and to the projecting ends of these the grip was attached. At the opposite end of the box frame a counterweight was attached which balanced about 700 lb. of the tunnel segment at 11 ft. radius.

The erector was revolved by two single-acting rams fixed horizontally to the back of the shield above the erector pivot through double chains and chain wheels keyed to the erector shaft.

The principal figures connected with the erector, assuming a water pressure of 5 000 lb. per sq. in., are:

Weight of heaviest tunnel segment...........	2 584 lb.
Weight of erector plunger and grip...........	616 "
Total weight to be handled by the erector ram..	3 200 "
Total force in erector ram moving from center of shield..................................	35 000 "
Total force in erector ram moving toward center of shield..................................	27 500 "
Weight at 11-ft. radius which is balanced by counterweight	700 "
Maximum net weight at 11-ft. radius to be handled by turning rams................	1 884 "
Total force of each rotating ram, at 5 000 lb. per sq. in.............................	80 000 "
Load at 11-ft. radius, equivalent to above......	3 780 "

When the shield was designed, a grip was also designed by which the erector could handle segments without any special lugs being cast on them. A bolt was passed through two opposite bolt holes in the circumferential flanges of a plate. The grip jaws closed over this bolt and locked themselves. The projecting fixed ends of the grip were for taking the direct thrust on the grip caused by the erector ram when placing a segment.

It happened, however, that there was delay in delivering these grips, and, when the shield was ready to start, and the grip was not forthcoming, Mr. Patrick Fitzgerald, the Contractor's Superintendent, overcame this trouble by having another grip made.

In this design, also, a self-catching bolt is placed through the segment and the grip catches the bolt. In simplicity and effectiveness in working, this new design eventually proved a decided advance on the original one, and, as a result, all the shields were fitted with the new grip, and the original design was discarded.

The great drawback to the original grip was that the plate swung on the lifting bolt, and thus brought a great strain on the bolt when

erecting a plate in the crown, whereas in the new one, the plate was held rigidly at right angles to the erector arm. The original design was able to handle both *A* and *B* segments, and key segments, without alteration; in the new design, an auxiliary head had to be swung into position to handle the key, but this objection did not amount to a practical drawback.

The operating floor from which the shield was controlled, and at which the valves were situated, was placed above the rams which rotate the erector, and formed a protection for them. The control of the shield rams was divided into four groups: the seven lower rams constituted one group, the upper five, another, and the six remaining on each side, the other two. Each group was controlled by its own stop and release valve. Individual rams were controlled by stop-cocks.

The control of the sliding platform rams was divided into two groups, of which all the rams on the upper floor made one, and all those in the lower floor, the other; here, again, each group had its own stop and release valve, and individual platforms were controlled by stop-cocks arranged in blocks from which the pipes were carried to the rams.

The in-and-out movements of the erector ram were controlled by a two-spindle, balanced, stop and release valve, controlled by a hand-wheel. The erector rotating rams were controlled by a similar valve, with four spindles, also operated by a single hand-wheel. Both wheels were placed inside the top shield pockets, and within easy reach of the operating platform.

The hydraulic pressure was brought through the tunnel by a 2-in. hydraulic pipe. Connection with the shield was made by a flexible copper pipe, the 2-in. line being extended as the shield advanced.

Land Tunnels.

General.

A short account will now be given of the main features of the "Land Tunnel" work, by which is meant all the part of the structure built without the assistance of the tunneling shield.

The Land Tunnels consist of about 977 ft. of double tunnel on the New York side and 230 ft. on the New Jersey side, or a total of 1 207 lin. ft. of double tunnel.

The general design of the cross-section consists of a semicircular arch, vertical side-walls and a flat invert. The tunnel is adapted for two lines of track, each being contained in its compartment or tunnel. The span of the arch is wider than is absolutely necessary to take the rolling stock, and the extra space is utilized by the provision of a side-walk or "bench" forming by its upper surface a gangway, out of the way of traffic, for persons walking in the tunnels, while embedded in its mass are a number of vitrified earthenware ducts, for high- and low-tension electric cables. The provision of this bench enables its vertical wall to be brought much nearer to the side of the rolling stock than is usually possible, thus minimizing the effects of a derailment or other accident. Refuge niches for trackmen, and ladders to the top of the bench are provided at frequent intervals. In cases where a narrow street limits the width of the structure, as on the New York side, the two tunnels are separated by a medial wall of masonry, thus involving excavation over the entire width of both tunnels, and in such case the tunnels are spoken of as "Twin Tunnels"; where the exigencies of width are not so severe, the two tunnels are entirely distinct, and are separated by a wall of rock. This type is found on the Weehawken side. The arches are of brick, the remainder of the tunnel lining being of concrete.

New York Land Tunnels.

A general account of the progress, method of work, plant used, and results obtained will now be given for the Land Tunnels. The work on these tunnels on the Manhattan side was carried on from the shaft at 11th Avenue and 32d Street.

The plans and designs for these tunnels are shown on Plate LXXXVI. In this short length of about 977 ft. there are no less than nine different kinds of cross-section. The reason for these changes is the fact that the two lines of track are here not straight and parallel to the center line between the tunnels, but are curved, although symmetrical about this center line. The various changes of section are to enable the tunnels to be built in straight lengths, thus avoiding the disadvantages attending the use of curved forms, and at the same time minimizing the quantity of excavation, an item which accounts for from 60 to 70% of the total cost of tunnels of this type. Of course, there are corresponding and obvious disadvantages in the adoption of many short lengths of different cross-sections, and these

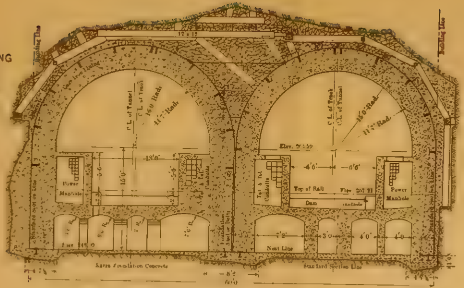
PLATE LXXXVI.
PAPERS, AM. SOC. C. E.
APRIL, 1910.
HEWETT AND BROWN ON
PENN. R. R. TUNNELS: THE NORTH RIVER TUNNELS.

TYPICAL SECTIONS
THIRTY-SECOND STREET TUNNELS
SHIELD CHAMBERS, ETC.

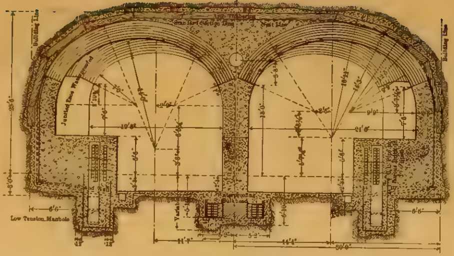
METHOD OF BONDING BRICK ARCHWORK

In order to obtain a bond between the different courses of brickwork, whenever a continuous joint was obtained through all courses, a double row of headers was put in.

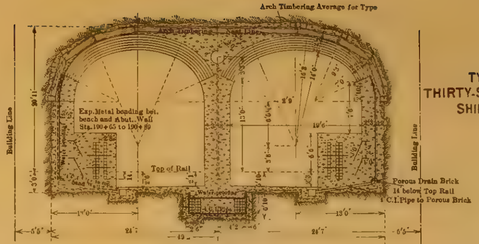
In order to have this uniform, the exact location of these joints was predetermined by calculation.



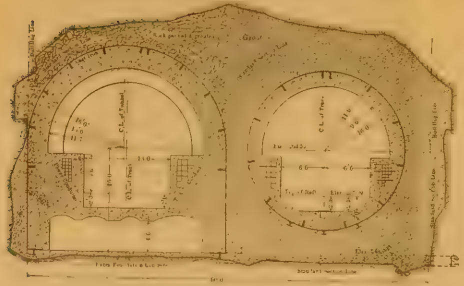
SHIELD CHAMBERS ARCH TIMBERING



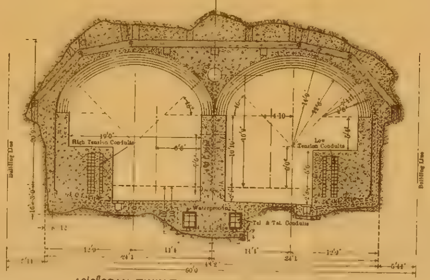
JUNCTION 19'6" AND 24'6" SPANS



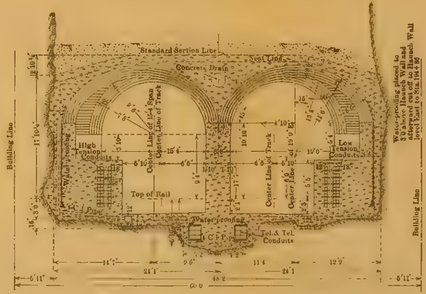
19'6" Span Twin Tunnels.

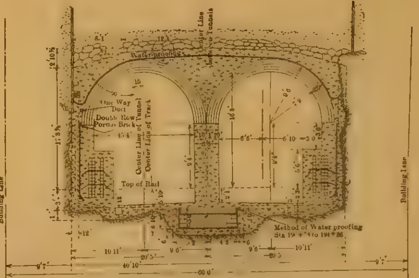


JUNCTION OF SHIELD CHAMBERS WITH RIVER TUNNELS



19'0" SPAN TWIN TUNNELS, ELLIPTICAL ARCHES





15'1" Span Twin Tunnels, Open Cut

disadvantages were well brought out in the course of the work; on the whole, however, they may be said to have justified their adoption. These New York Land Tunnels were divided into three contracts, viz.: From Station 190 + 15 (the Portal to the open work of the Terminal Station at the east side of Tenth Avenue, New York City) to Station 197 + 60, called "Section Gy-East." The next contract, called "Section Gy-West Supplementary," extended from Station 197 + 60 to Station 199 + 20, which is the east side of Eleventh Avenue. The third contract was called "Section Gy-West," and extended from Station 199 + 20 to Station 231 + 78 (the dividing line between the States of New York and New Jersey). Thus, for nearly all its length, this contract consists of shield-driven tunnel. The portion between Stations 199 + 20 and 199 + 91.5, however, was of the Land Tunnel type, and therefore will be included here. A fourth contract extended from Station 231 + 78 to the Weehawken Shaft at Station 263 + 50, and of this all but 230 ft. was of the shield-driven type, only the portion next to the Weehawken Shaft being of the Land Tunnel type.

The four contracts were let to one contractor (The O'Rourke Engineering Construction Company), and the work was carried on simultaneously in all four, so that the division into contracts had no bearing on the methods of work adopted, and these will now be described as a whole and with no further reference to the different sections.

Excavation.

Work was started on the New York side on April 18th, 1904, the Weehawken shaft being at that date still under construction. As will have been noted in the description of the shafts, the contractor found a shaft already prepared for his use, and cross-drifts at grade and at right angles to the future tunnels, and extending across their entire width. The first essential was to get access to the shield chambers, which were to lie about 330 ft. to the west of the shaft, so that the construction of these enlargements in which the shields for the subaqueous tunnels were to be built might be finished as soon as possible and thus allow the earliest possible start to be made with the shield-driven tunnels.

With this in view, two bottom headings, on the center line of each of the two tracks, were driven westward from the western cross-heading at the foot of the shaft. When about 138 ft. had been made in this

way, the two headings were brought together and a break-up was made to the crown level of the tunnel, as the depth of rock cover was doubtful. From this break-up a top heading was driven westward to Station 200 + 30. While widening the heading out at Station 200 + 20 the rock was penetrated on the south side. The exposed wet sand and gravel started to run, and, as a consequence, a change in design was made, the shield chambers (and consequently the start of the shield-driven tunnels) being moved eastward from their original location 133 ft. to their present location. A certain amount of time was necessarily spent in making these changes of design, which involved a rearrangement of the whole layout from the Terminal Station to the start of the River Tunnels. On July 5th, 1904, however, the new design was formally approved. No sooner had this been decided than a strike arose on the work, and this was not settled until August 1st, 1904, but from that time the work progressed without delay. No further reference will be made to the work in the shield chambers, as that will come under the heading of "River Tunnels," being of the segmental, cast-iron lined type.

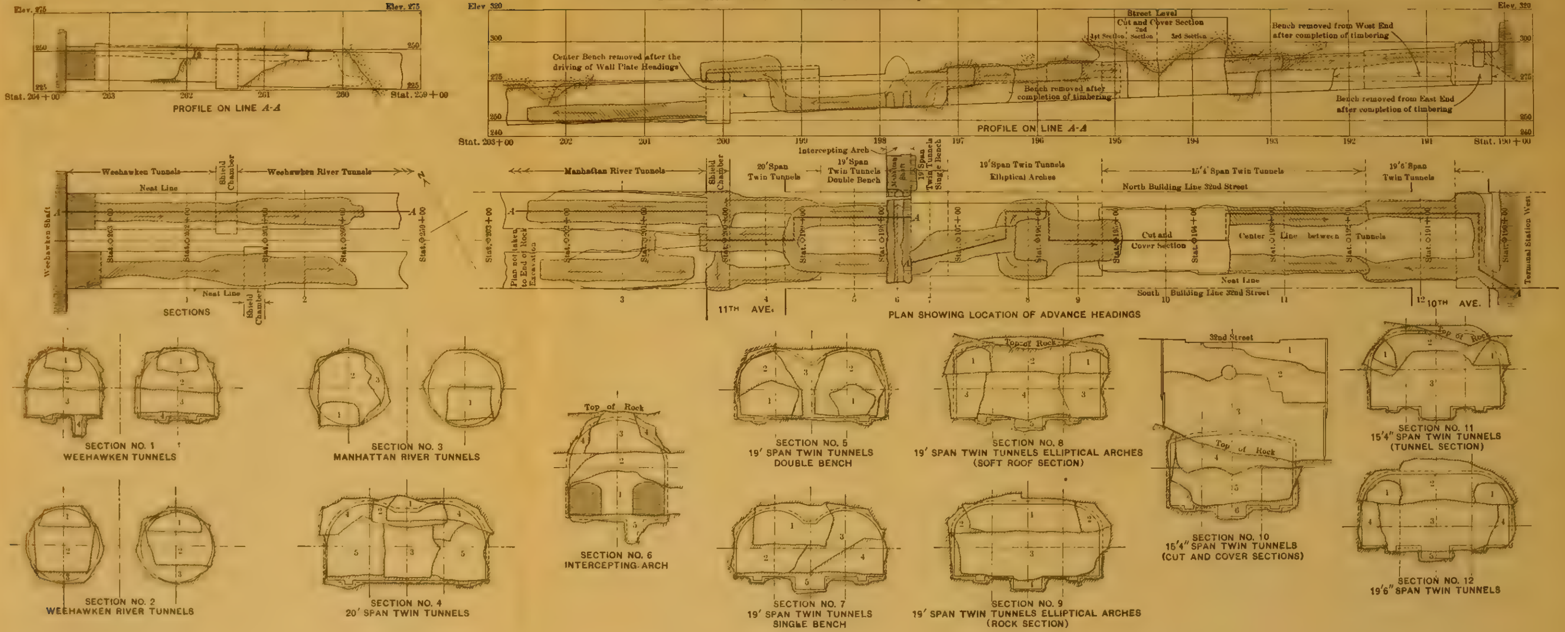
A top heading was now driven over the original bottom heading west of the shaft, and at the same time the original cross-drifts from the shaft were amalgamated with and broken down by a heading driven at the crown level of the "Intercepting Arch" which here cuts across the ordinary run of tunnel at right angles and affords access to the tunnels from the shafts.

The excavation of the upper portion of the intercepting arch at its southern end gave some trouble, and caused some anxiety, as the rock cover was penetrated and the wet sand and gravel were exposed. This made it necessary to timber all this section heavily, and the tracks of the New York Central Railroad directly above were successfully supported. The general way in which this timbering was carried out will be described under the head of "Timbering."

Meanwhile, the excavation of the tunnels west of the intercepting arch was continued until the North and South Tunnels were taken out to their full outlines, leaving a core of rock between them. This core was gradually removed, and timbering supporting the rock above the middle wall was put in as excavation went on. The ground, which was entirely of micaceous schist, typical of this part of Manhattan, seamed with veins of granite, was rather heavy at the west end, or

GENERAL METHOD OF EXCAVATION ADOPTED FOR LAND TUNNELS

NOTE:- The Sub-divisions of each Cross-section are numbered in order as excavated
Sections Cross-hatched were excavated under previous contracts.



adjacent to the shield chambers, and required complete segmental timbering across the whole span. One heavy fall of rock in the core-wall between the North and South Tunnels took place on November 2d, but fortunately did not extend beyond the limits of the permanent work. On November 7th, 1904, the excavation east of the intercepting arch was begun by driving a bottom heading in the South Tunnel. This was continued to Station 197 + 14 and then was taken up to the crown level and worked as a top heading with the view of keeping track, by making exploratory borings upward from the roof at frequent intervals, of the rock surface, which was here irregular and not known with any degree of certainty. The work was not pressed with any vigor, because all efforts were then being bent toward excavating from the River Tunnels as much rock as possible. In Section Gy-East the conditions were exceptionally variable, as the rock was subject to sudden changes from a soft crumbling mica schist to broad bands of hard granite, and, in addition, the rock surface was very irregular, and, for a good length of this section, was below the crown of the tunnel, a condition which led to the adoption of the cut-and-cover method for part of the work.

The irregularity in conditions called for varying methods of procedure, but in general the methods were as shown on Plate LXXXVII, and described as follows:

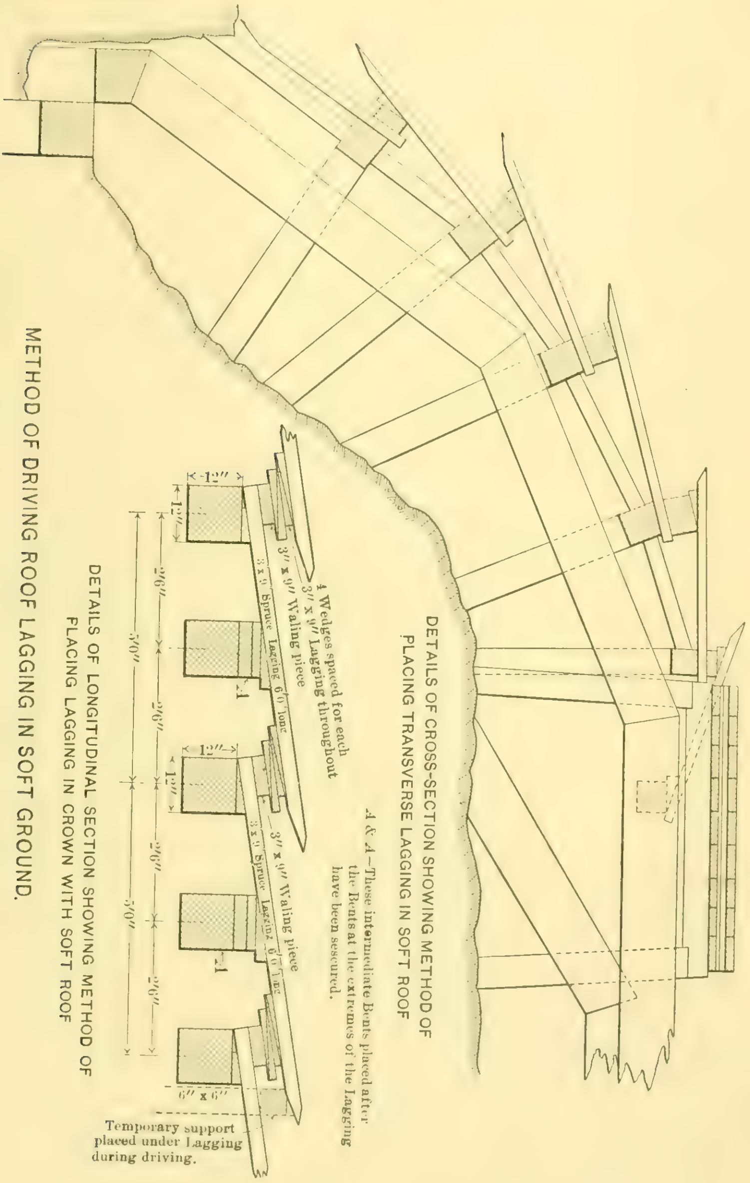
In Solid Rock.—Where there was plenty of good rock cover, a top middle heading was driven, which was afterward widened out to the full cross-section of the twin tunnel arches. If necessary, a few lengths of segmental timbering were put in before taking down the bench, which was generally kept some 40 or 50 ft. behind the breast of the heading. After the bench was down, the middle conduit trench was excavated and the trimming done.

In Soft Rock.—Where there was not enough rock cover, or where there was actual soft ground in the roof, wall-plate headings at the springing line level were driven ahead of the remainder of the work. The wall-plates were laid in these, the roof was taken out in short lengths, and segmental timbering spanning from wall-plate to wall-plate was put in. The roof being thus held, the bench excavation proceeded without trouble. Where the rock was penetrated and soft ground showed in the roof, poling boards were driven ahead over the crown-bars, as shown in Fig. 4.

Cut-and-Cover Work.—After some 225 ft. had been driven from the intercepting arch, it was found that the crown of the tunnel was continually in soft ground. To ascertain the extent of this condition the contractor decided to make soundings as far as Tenth Avenue, which was done by sinking trial pits and making wash-borings in the street. These soundings showed that there would be soft ground in the crown from Station 194 + 75 to Station 194 + 25 (at one point to a depth of 12 ft. below the crown), and on each side of this section the cover was insufficient from Station 193 + 58 to Station 195 + 30. This condition being known, it was decided to adopt cut-and-cover work for this length, the principal reasons being that repairs to sewers, streets, and drains would be no more, and probably less, expensive than with the tunnel method; the underpinning of a heavy brick brewery building adjoining the works on the north side would be facilitated, and the opening in the street, through which muck and materials could be handled, would relieve the congested shaft, through which the large volume of muck from the River Tunnels was then being conveyed. On the other hand, the cut-and-cover method was adversely affected by the presence of a heavy timber trestle built down the south side of the street and over which passed all the excavation from the Terminal Station, amounting to a very heavy traffic. As this trestle had to be supported, it complicated the situation considerably. Very little active progress was made between June, 1905, and April, 1906, as the contractor's energies during that time were much taken up with the progress of the shield-driven tunnels. In April, 1906, preparations were made to start a 50-ft. length of open cut, rangers being fixed and sheathing driven; and the sewer which ran down the middle of this street was diverted to the outside of the open-cut length.

April and May were occupied in driving the sheathing down to rock, supporting the trestle, underpinning the adjoining brewery, and excavating the soft material above the rock. On June 2d, 1906, rock was reached, and, by July 31st, the excavation was down to subgrade over nearly the whole 50 ft. in the first length. In the meantime another length was opened up, and eventually a third.

The surface of the rock now seemed to be rising, and the heavy buildings had been passed, so that tunneling was reverted to for the rest of the work, though many difficulties were caused by soft rock in the roof from time to time.



METHOD OF DRIVING ROOF LAGGING IN SOFT GROUND.

Fig. 4.

When the excavation for the open-cut work of the Terminal Station had advanced to the line of Tenth Avenue, the contractor started a heading from this point and drove westward under Tenth Avenue until the headings driven eastward from the cut-and-cover portion, were met.

This was done to expedite the work under Tenth Avenue, where the ground was not very good, where there were several important gas and water mains in the street, and where, moreover, the tunnels were of exceptionally large span (24 ft. 6 in.), making a total width of some 60 ft. for the excavation. The excavation for the New York Tunnels was practically finished in January, 1908.

Drilling and Blasting.—The foregoing short description will serve to show in a general way the scheme adopted in making the excavation. A few details on drilling and blasting methods may not be out of place.

Percussive drills run by air pressure were used. They were Ingersoll-Sergeant, Nos. 3½, A-86, C-24, and F-24. The air came from the high-pressure compressor previously described. This compressor, without assistance, could supply air for nine drills, but, when fed by compressed air from the lower pressure, its capacity was increased three or four times.

The air was compressed to 100 lb. per sq. in. in the power-house, and was delivered at about 80 lb. per sq. in. at the drills. A 3-in. air line was used. The drill steel was 1⅛- to 1⅝-in. octagonal. The holes were about 3¼ in. in diameter at starting and 2⅝ in. at the full depth of 10 ft. The powder used on the New York side was 40% Forcite, the near presence of heavy buildings and lack of much rock cover necessitating light charges and many holes spaced close together.

To compensate the contractor for the inevitable excavation done outside the neat lines of the masonry lining, the excavation was paid for to the "Standard Section Line" which was 12 in. outside the neat lines on top and sides and 6 in. outside at the bottom of the cross-section. The actual amount of excavation done was about 11% greater than that paid for. The distance excavated beyond the neat line, because of the very heavy timbering necessary, was about 2.1 ft. instead of the 1 ft. allowed, and at the bottom about 0.85 ft. instead of the 0.50 ft. paid for.

For a period of 5 months detailed records were kept of the drilling

and blasting. About 12 900 cu. yd. of excavation are included. A sketch and table showing the method of driving the heading, the number and location of the holes drilled, and the amount of powder used, is given in Fig. 5. From this and similar figures the information in Table 5 is derived.

TABLE 5.

Portion of excavation.	Feet of Hole Drilled per Cubic Yard of Excavation.			Pounds of Powder Used per Cubic Yard of Excavation.		
	15-ft. 4-in. span—twin tunnel.	19-ft. 6-in. span—twin tunnel.	24-ft. 6-in. span—twin tunnel.	15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.
Wall-plate heading*......	13.0	10.97	10.97	3.77	2.85	2.85
Total heading*............	7.87	8.17	7.81	2.31	2.02	1.78
Bench and raker bench*..	5.97	6.15	7.56	0.94	0.93	1.13
Trench*....................	9.82	15.96	18.10	1.84	2.49	2.73
Average for section*......	6.69	7.43	8.95	1.28	1.30	1.45
Actual amount†...........	6.82	7.27	8.95	1.22	1.24	1.27

*Figures taken from typical cross-sections.
†This gives the actual amount of drilling done and powder used per cubic yard for the whole period of 5 months of observation, but as this length included 280 ft. of heading and only 220 ft. of bench, the average figures (for powder especially) are too low.

Table 6 gives the rate and cost of drilling, and the cost of powder. It will be seen that the average rate of drilling was 2.71 ft. per hour per drill or 27.1 ft. per drill per shift.

Table 7 shows the result of observation as to the time taken in various subdivisions of the drilling operations. These observations were not carried on for a long enough period to give correct results, but the percentages of time spent on each division of the operation are believed to be about right. The headings of this table are self-explanatory. The necessary delays include all time spent in changing bits, making air-line connections, etc. The unnecessary delays are stoppages caused by lack of supplies or insufficient air pressure.

By Table 6 it will be noticed that the cost of labor for drilling and sharpening steels was about $0.29 per lin. ft. of hole drilled. The total cost, including repairs, supply of air, etc., came to about $0.38, as will be seen from Table 8.

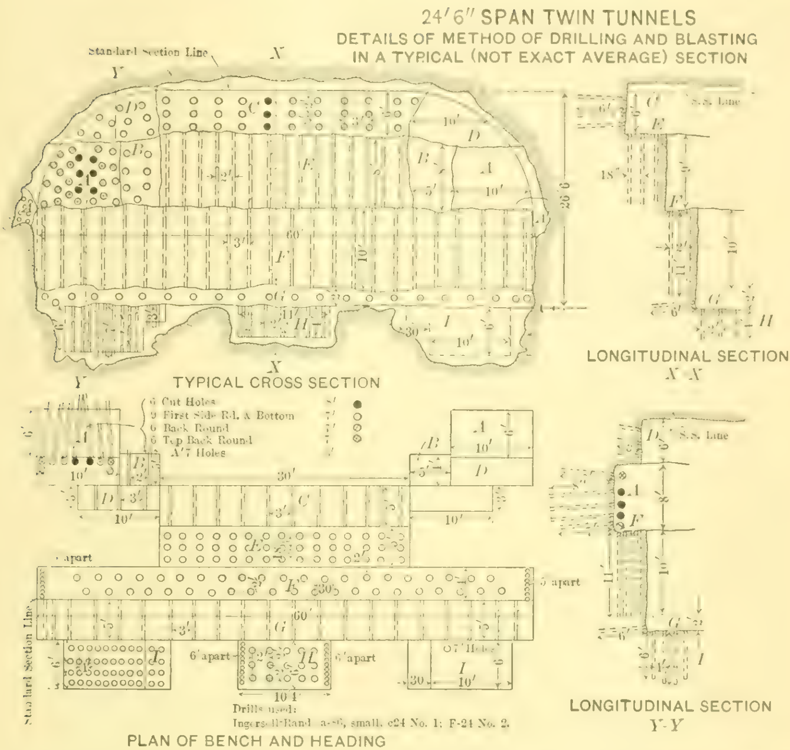
Timbering.—On the New York side nearly the whole length of the excavation needed timbering, to a greater or less extent, and for the most part required timbering of quite a heavy type.

TABLE 6.—ROCK TUNNEL EXCAVATION UNDER 32D STREET, EAST OF CUT-AND-COVER SECTION. DRILLING AND BLASTING.—DETAILED COST OF LABOR IN DRILLING, ALSO QUANTITY AND COST OF POWDER USED.

Type.	Date.	Drilling and Blasting. Total feet drilled.			No. of drill shifts. (10-hour.)			Feet drilled per man per hour.			Quantity of excavation, in cubic yards.		Cost of labor only. Drilling and sharpening.				Powder Used. Total quantity.	Cost per cubic yard at 11 cents per pound.	
	1907	Heading.	Bench.	Total.	Heading.	Bench.	Total.	Heading.	Bench.	Total.	Actual.*	Paid for †	Total. $	Per linear feet. $	Per cubic yard. Actual. $	Per cubic yard. Paid for. $	Pounds.	Actual. $	Paid for. $
Ke.	May	2 971	5 578	8 549	98	204	302	3.031	2.734	2.831	1 736	1 664	2 331	0.27	1.34	1.40	1 595	0.10	0.10
	June	2 093	6 194	8 287	85	223	308	2.462	2.777	2.691	809	698	2 440	0.29	3.01	3.49	1 960	0.27	0.31
	July	....	7 627	7 627	......	268	268	......	2.845	2.845	1 022	960	2 031	0.26	1.98	2.11	966	0.10	0.11
	Aug	....	2 552	2 552	......	95	95	......	2.688	2.688	743	716	640	0.25	0.86	0.89	430	0.06	0.07
	Sept.	....	2 133	2 133	......	79	79	......	2.700	2.700	238	238	533	0.25	2.24	2.24	280	0.13	0.13
	Total.....	5 064	24 084	29 148	183	869	1 052	2.767	2.77	2.77	4 548	4 276	7 975	0.27	1.75	1.87	5 231	0.13	0.13
Ki.	May	6 976	....	6 976	216	....	216	3.229	......	3.229	614	527	1 604	0.23	2.61	3.04	1 230	0.22	0.26
	June	4 089	....	4 089	135	....	135	3.029	......	3.029	357	259	1 234	0.30	3.45	4.76	1 036	0.32	0.44
	July	....	3 733	3 733	......	140	140	......	2.666	2.666	530	404	1 084	0.29	2.04	2.68	550	0.11	0.15
	Aug.	....	6 715	6 715	......	249	249	......	2.769	2.769	925	890	1 901	0.28	2.05	2.13	905	0.10	0.11
	Estim. ..	....	14 742	14 742	......	546	546	......	2.700	2.700	3 254	2 908	4 570	0.31	1.40	1.57	2 470	0.08	0.09
	Total	11 065	25 190	36 255	351	935	1 286	3.152	2.694	2.819	5 680	4 988	10 393	0.29	1.83	2.08	6 191	0.12	0.14
Ko.	May	....	1 617	1 617	......	55	55	......	2.921	2.921	250	188	471	0.29	1.88	2.50	376	0.17	0.22
	June	....	2 948	2 948	......	107	107	......	2.755	2.755	496	347	883	0.29	1.78	2.54	357	0.08	0.11
	July	....	3 734	3 734	......	131	131	......	2.850	2.850	626	606	1 003	0.27	1.60	1.65	609	0.11	0.11
	Aug.	....	8 260	8 260	......	290	290	......	2.848	2.848	718	709	2 161	0.26	3.00	3.04	918	0.14	0.14
	Estim....	....	4 787	4 787	......	285	285	......	1.680	1.680	605	535	2 397	0.50	3.96	4.48	762	0.14	0.16
	Total.....	....	21 346	21 346	......	868	868	......	2.460	2.460	2 695	2 385	6 915	0.32	2.57	2.90	3 022	0.12	0.14
Grand Total....		16 129	70 620	86 749	534	2 672	3 206	3.020	2.710	2.710	12 923	11 649	25 283	0.29	1.96	2.17	14 444	0.12	0.14

The work done during the 5 months when these analyzed cost figures were kept includes 280 ft. of bench and 220 ft. of heading. This excess of bench over heading causes the general average amounts per cubic yard to be too low.

* Actual amount of excavation. † Amount of excavation paid for.



Sub divisions	Volume of each sub-division paid for	No. of sets of holes	No. of holes in set	No. of times fired	Total lbs. of powder per hole fired	Linear feet of tunnel broken	Total length drilled	Total length of similar headings	Length drilled per linear foot of tunnel	Cu. yds. per linear foot of tunnel	Total feet drilled per cubic yard	Total lbs. of powder per linear foot of tunnel	Total lbs. of powder per foot drilled	Total lbs. of powder per cubic yard
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
									$\frac{\Sigma c+d}{g}$	$\frac{b+i}{g}$	$\frac{j}{k}$	$\frac{c+d+f}{g}$	$\frac{m}{j}$	$\frac{m}{k}$
A	17.775	• 1	6	3	4.50									
		⊙ 1	9	1	1.50									
		⊘ 1	6	1	1.00									
		⊗ 1	6	1	0.75	6.0	195	2	65.00	5.925	10.97	17.00	0.261	2.848
A'	1.00	2	3-4	1	0.25	5.0	21	[illegible]	8.40	0.400	21.00	0.70	0.166	1.750
B	5.925	• 2	3-4	1	1.00	4.0	35	2	17.50	2.962	5.90	3.50	0.200	1.181
C		1	3	2	1.125									
	33.33	4	7	1	1.125	5.0	186	1	37.20	6.666	5.58	6.975	0.187	1.046
D	6.665	2	5-6	1	0.75	3.0	33	2	22.00	4.444	4.95	5.500	0.250	1.237
	Total for Heading								150.10	20.397	7.81	33.675	0.227	1.778
E	50.00	9.0	5	1	1.50	5.0	[illegible]	1	81.00	10.000	8.10	13.500	0.167	1.350
F	88.88	10.5	4	2	1.50									
		+ 5.0	4	1	1.50	4.0	[illegible]	1	170.50	22.222	[illegible]	23.230	0.136	1.046
G	22.22	5.5	4	2	1.00	5.0	132	1	26.40	4.444	5.94	4.100	0.166	0.990
	Total for Bench								[illegible]	36.666	[illegible]	41.150	0.150	1.133
H	9.77	5	3	1	0.50									
		4	6	1	0.50	6.0	[illegible]	1	26.00	1.628	15.96	3.250	0.125	1.995
I	26.66	8	5	1	1.00	6.0	[illegible]	2	84.00	4.444	18.90	13.333	0.158	3.000
	Total of Trench								110.00	6.072	18.10	16.583	0.151	2.731
	Total for Whole Section								[illegible]	[illegible]	8.95	91.408	0.172	1.446

\+ line holes Powder taken at 0.5 lb. per stick

FIG. 5.

TABLE 7.—ANALYSIS OF DRILLING TIME ON SECTION GY-EAST.

Position in Section.	Nature of Rock.	No. of Drill Shifts observed for average.	AVERAGE TIME TAKEN: Setting up.	Drilling.	Necessary delays.	Unnecessary delays.	Taking down machine.	Loading and firing.	Total drilling.	Mucking.	Total.	FEET DRILLED. Per shift.	Per working hour.
			h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	....	....
Heading..................	Quartz..................	8	0 : 38	4 : 52	1 : 40	....	0 : 05	0 : 04	7 : 19	2 : 41	10 : 00	22.0	2.86
Heading..................	Hard mica schist......	1	0 : 15	8 : 00	1 : 45	....	....	....	10 : 00	....	10 : 00	42.0	4.20
Bench....................	Quartz..................	23	1 : 23	5 : 57	2 : 23	0 : 05	0 : 05	0 : 07	10 : 00	....	10 : 00	25.9	2.59
Bench....................	Medium mica schist....	16	1 : 10	6 : 08	1 : 50	0 : 12	0 : 07	0 : 07	9 : 34	0 : 26	10 : 00	22.22	2.32
Center trench...........	" " "	10	0 : 58	5 : 53	1 : 33	0 : 06	0 : 12	0 : 30	9 : 12	0 : 48	10 : 00	22.0	2.39
Center trench...........	Soft " "	9	1 : 10	6 : 40	1 : 17	0 : 10	0 : 20	0 : 23	10 : 00	....	10 : 00	26.44	2.64
General average..............................		67	1 : 08	5 : 58	1 : 53	0 : 07	0 : 09	0 : 12	9 : 27	0 : 33	10 : 00	24.1	2.54
Percentage....................................		......	11.3%	59.7%	18.9%	1.1%	1.5%	2%	94.5%	5.5%	100%	....	....

TABLE 8.—ANALYZED COST OF DRILLING.

Item of Cost.	Cost per Foot of Hole Drilled.				Cost per Drill Shift.			
	15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.	Average.	15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.	Average.
Drilling labor	$0.25	$0.28	$0.31	$0.28	$6.95	$7.75	$7.60	$7.45
Sharpening	0.02	0.02	0.01	0.016	0.53	0.42	0.34	0.43
Drill steel (5 in. per drill shift)	0.007	0.007	0.006	0.007	0.19	0.20	0.15	0.19
Drill repairs	0.02	0.02	0.02	0.02	0.61	0.59	0.42	0.54
High pressure air	*0.05	0.04	0.07	0.07	1.39	1.86	1.67	1.82
Totals	$0.35	$0.38	$0.41	$0.385	$9.67	$10.82	$10.18	$10.43

* This is an estimated figure, ascertained by taking a proportion of the whole charge for plant running.

General Methods.—Whenever any considerable support was needed for the ground, segmental timbering was used. In most cases, this was supported by wall-plates at the springing line, and was set with an allowance for settlement, so that it would be clear of the work when the masonry lining was put in. As the twin-tunnel section involved the excavation of the North and South Tunnels at the same time, the cross-section of the upper part of the excavation consisted of two quadrants rising from the springing line and connected at the top by a horizontal piece from 19 to 28 ft. in length. This made a rather flat arch to support by timbering.

The timber for the segmental work was 12 by 12-in. yellow pine. In light ground the bents were spaced at 5-ft. centers, in heavy ground 2-ft. 6-in. centers.

When the soft ground in the roof was struck, posts had to be used in the heading to support the caps. When the bench was removed, the posts were replaced by others down to the bottom of the excavation. These long posts were a great hindrance to all the work, and each replacement of short posts by long ones meant a settlement of the caps; consequently, it was decided to use in the section east of the cut-and-cover, where all the ground was heavy, a temporary inner bent of segmental timber, within and reinforcing the permanent bent, and resting on separate wall-plates. This is shown by Fig. 6. These temporary bents were inside the work, and were removed as the arch was built. However, the caps settled considerably in some cases, so that it was not possible to do away with posting entirely.

In heavy ground the caps were set about 1 ft. above the neat line of the crown of the brick arch, in some cases they were set only 6 in. above, but the settlement was often more than this, causing great trouble in cutting out the encroaching timber when the arch had to be built.

In the tunnels east of the cut-and-cover portion, wall-plate headings were driven (shown by areas marked *A* on Fig. 5), and, when a length of wall-plate had been set, the full-width heading was advanced a foot

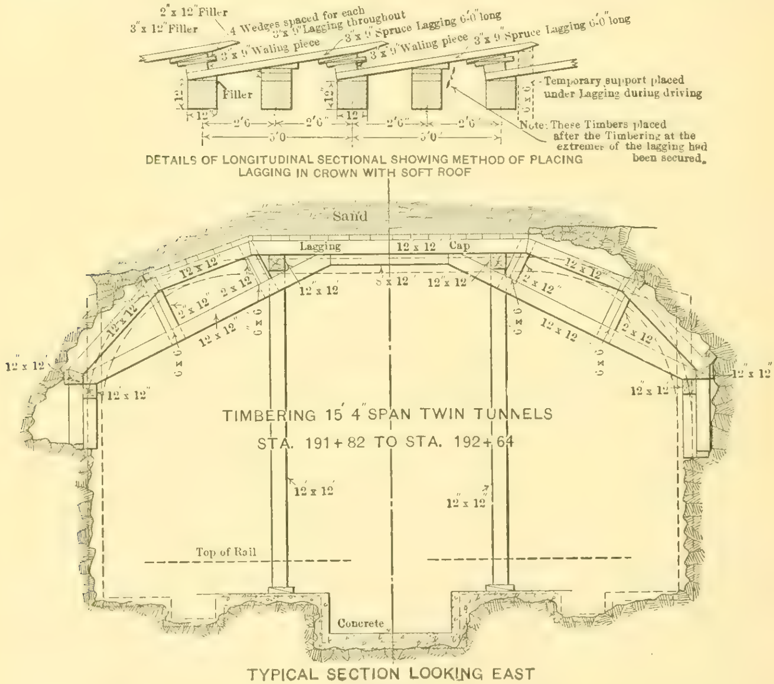


Fig. 6.

or two at a time, the timber segmental bents being set up as soon as possible; lagging was then driven over the cap into the soft ground. Fig. 6 shows the double set of segmental bents adopted in the 15-ft. 4-in. twin tunnels east of the cut-and-cover section.

When the soft ground came down so low as to interfere with the excavation of the wall-plate headings, a small heading was driven into the soft ground on the line of the ends of the caps, and lagging was driven down from this to the wall-plate heading, as illustrated in Fig. 4.

In the 19-ft. 6-in. tunnels the wall-plate for the inner bent was supported by a side-bench, termed the "Raker" bench. This was left in position until the rest of the bench and the middle subgrade conduit trench had been excavated; it was then possible to support the caps by two rows of posts from subgrade level, take out the inner bents, and excavate the raker bench.

The 24-ft. 6-in. twin tunnels, which are at the extreme eastern end of this section, adjoining the open-cut work of the Terminal Station, and under Tenth Avenue, were driven from the Terminal Station-West, and the timbering had to be made very secure on account of the pipes and sewers in the street above. Detailed records were kept of the amount of timber used and the cost of labor and material expended in timbering. These records cover the same portion of tunnel as that for which the detailed records of drilling costs, previously referred to, were kept. These records are shown in Tables 9 and 10. It will be noted that the timber used in blocking, that is, filling up voids outside the main timbering, amounted to more than two-thirds of the total timber, and that the cost of labor in erecting the timbering exceeds the prime cost of the timber by about one-third. The following distinction is made between permanent and temporary timbering: The permanent timbering is that which is concreted in when the masonry is built; the temporary consists of the lower bents and posts, which have to be removed when the masonry is built.

Force Employed in Excavation.—A typical day's working force for drilling, blasting, mucking, and timbering is shown in Table 11.

Where there was any large quantity of soft ground in the roof, the timber gang was much larger than shown in Table 11, and was helped by the mucking gang. The drillers did most of the mucking out of the heading before setting up the drills.

Excavation of Weehawken Rock Tunnels.—This subject may be dismissed in a few words, as very few features of interest were called into play. The rock was of good quality, being the sandstone typical of this part of the country. Little or no timbering was needed, there were no buildings above the tunnel to be taken care of, and large charges of powder could be used.

Work was begun on September 1st, 1904, immediately on the completion of the work on the shaft. The North and South Tunnels in this case are completely independent, as will be seen from Plate

TABLE 9.—SUPPLEMENTARY ANALYSIS OF TIMBERING, ROCK TUNNEL EXCAVATION UNDER 32D STREET, EAST OF CUT-AND-COVER SECTION.

ANALYZED COST OF TIMBERING, PER FOOT RUN AND PER BENT.

	PERMANENT TIMBERING.						TEMPORARY TIMBERING.								GRAND TOTAL.			
	Lumber in feet, B. M.			Cost, in dollars.			Lumber in feet, B. M.			Cost, in dollars.					Lumber in feet, B. M.	Cost, in dollars.		
	Upper Bent.	Blocking.	Total.	Lumber.	Labor.	Total.	Lower Bent.	Blocking.	Total.	Lumber.	Erection labor.	Removal labor.	Total labor.	Total.		Lumber.	Labor.	Total.
Ke																		
Per foot run of tunnel...........	274	294	568	23.75	37.50	61.25	479	193	672	29.13	28.85	8.29	37.14	66.27	1 240	52.88	74.64	127.52
Per bent, 2 ft. 6 in., center to center..........................	685	735	1 420	59.38	93.75	153.13	11.97	483	16.80	72.81	72.13	20.73	92.86	165.67	3 100	132.19	186.61	318.80
Per cubic yard excavation.......	7.8	8.3	16.1	0.67	1.06	1.73	13.6	5.5	19.1	0.82	0.82	0.23	1.05	1.87	35.2	1.49	2.11	3.60
Ki																		
Per foot run of tunnel..........	227	164	391	16.84	12.82	29.66	186.33	42.80	229.13	9.65	10.38	9.74	20.12	29.77	6 20	26.49	32.94	59.43
Per bent, 3 ft. 6 in., center to center..........................	830	601	1 431	61.56	46.88	108.44	681.25	156.50	837.75	35.31	37.97	34.09	72.06	107.37	22 69	96.87	118.94	215.81
Per cubic yard excavation......	5.3	3.8	9.1	0.39	0.30	0.69	4.33	0.99	5.32	0.22	0.24	0.23	0.47	0.69	14.4	0.61	0.77	1.38
Ko																		
Per foot run of tunnel...........	261	408	669	28.00	29.79	57.79	350	61	411	18.45	20.83	12.16	32.99	51.44	1 080	46.45	62.78	169.23
Per bent, 3 ft. 8 in., center to center..........................	962	1 508	24.70	103.38	110.00	213.38	1 291	227	1 518	68.16	76.92	44.59	121.51	189.67	3 988	171.54	231.50	403.04
Per cubic yard excavation.......	4.1	6.5	10.5	0.44	0.47	0.91	5.5	1.0	6.5	0.29	0.33	0.19	0.52	0.81	17.1	0.73	0.99	1.72

TABLE 10.—TIMBERING:—DETAILED COST OF TIMBER, LABOR, AND SUPERINTENDENCE. ROCK TUNNEL EXCAVATION UNDER 32D STREET, EAST OF CUT-AND-COVER SECTION.

	DATE.	Timber Used, in Feet, B. M.			Excavation in Cubic Yards.		Cost of Timber.			Cost of Labor.	Total Cost.	Cost per Cubic Yard (Actual).			Cost per Cubic Yard (Paid for).			Cost, per 1 000 Ft., B. M., of Total Timber.		
		Main timber.	Blocking timber.	Total timber.	Actual.	Paid for.	Main.	Block.	Total.			Timber.	Labor.	Total.	Timber.	Labor.	Total.	Total timber.	Labor.	Total.
	1907	a	b	c	d	e	f	g	h	i	j	$\frac{h}{d}$	$\frac{i}{d}$	$\frac{j}{d}$	$\frac{h}{e}$	$\frac{i}{e}$	$\frac{j}{e}$	$\frac{h}{c}$	$\frac{i}{c}$	$\frac{j}{c}$
Ke	May.......	18 016	15 234	33 250	1 736	1 664	$810	$565	$1 375	$1 792	$3 167	$0.79	$1.03	$1.82	$0.82	$1.07	$1.90	$41 35	$53.89	$95.24
	June......	14 048	11 528	25 576	809	698	630	457	1 087	1 576	2 663	1.34	1.95	3.29	1.55	2.25	3.81	42.50	61.62	104.12
	July	20 092	7 339	27 431	1 022	960	900	300	1 200	1 580	2 780	1.16	1.55	2.72	1.25	1.64	2.89	43.74	57.60	101.34
	August ...	6 485	2 632	9 117	743	716	290	110	400	300	700	0.53	0.40	0.94	0.57	0.41	0.98	43.87	32.90	76.77
	Sept	1 632	2 224	3 856	238	238	73	94	167	60	227	0.70	0.25	0.95	0.70	0.25	0.95	43.31	15.56	58.87
	Removal..	....	......	....	......	......	......	......	......	663	663	......	......	......	......	......	......	......	......	....
	Total......	60 273	38 957	99 230	4 548	4 276	$2 703	$1 526	$4 229	$5 971	$10 200	$0.91	$1.51	$2.22	$1.00	$1.40	$2.40	$42.62	$60.19	$102.81
Ki	May.......	....	3 537	3 537	614	527	......	$150	$150	$100	$250	$0.24	$0.16	$0.40	$0.28	$0.19	$0.47	$42.41	$28.27	$70.68
	June......	300	......	300	357	259	$14	......	14	44	58	0.04	0.12	0.16	0.05	0.17	0.22	46.66	146.33	193.33
	July	7 776	5 811	13 587	530	404	350	233	583	525	7 108	1.10	0.99	2.09	1.44	1.30	2.74	42.91	88.64	81.54
	August ...	19 712	5 702	25 414	925	890	887	220	1 107	1 018	2 125	1.20	1.10	2.30	1.24	1.14	2.38	43.56	40.06	83.61
	Sept	20 556	9 218	29 774	1 585	1 501	925	325	1 250	1 028	2 278	0.79	0.65	1.44	0.83	0.68	1.51	41.98	34.53	76.51
	Removal..	....	......	....	1 669	1 407	......	......	......	1 139	1 139	......	0.68	0.68	......	0.81	0.81	......	......	....
	Total......	48 344	24 268	72 612	5 680	4 988	$2 176	$928	$3 104	$3 854	$6 958	$0.55	$0.68	$1.23	$0.63	$0.77	$1.40	$42.75	$53.09	$95.84
Ko	May.......	4 332	8 788	13 120	250	188	$175	$366	$561	$303	$864	$2.24	$1.21	$3.45	$3.00	$1.61	$4.61	$42.76	$23.10	$65.86
	June......	7 132	10 017	17 149	496	347	324	396	720	562	1 282	1.45	1.13	2.58	2.07	1.61	3.68	41.98	32.77	74.75
	July	3 070	200	3 270	626	606	134	10	144	156	300	0.23	0.25	0.48	0.23	0.26	0.49	44.04	47.70	91.74
	August ...	10 704	2 102	12 806	718	709	481	80	561	727	1 288	0.78	1.01	1.79	0.80	1.02	1.82	43.80	56.77	100.57
	Sept	2 400	245	2 645	396	324	108	8	116	400	516	0.29	1.01	1.30	0.36	1.23	1.59	43.85	151.23	195.08
	Removal..	....	......	....	209	211	......	......	......	585	585	......	2.56	2.56	......	2.54	2.54	......	......	....
	Total......	27 638	21 352	48 990	2 695	2 385	$1 242	$860	$2 102	$2 683	$4 785	$0.78	$1.00	$1.78	$0.88	$1.12	$2.00	$42 91	$54.75	$97.65
	Grand total	136 255	84 577	220 832	12 923	11 649	$6 121	$3 314	$9 435	$12 508	$21 943	$0.73	$0.97	$1.70	$0.81	$1.07	$1.88	$42.73	$56.65	$99.38

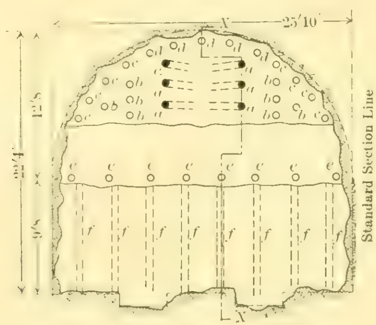
LXXXVIII. The procedure adopted was to drive a top heading on the center line of each tunnel and to break down the bench from this. The drilling was at first supplied with steam power from a temporary plant, as the contractor was at that time installing his permanent plant, which was finished at the end of November, 1904. At this time the rate of advance averaged 3½ lin. ft. of full section per day of 24 hours. By the end of January the Weehawken rock tunnels were completely excavated, and by the middle of April, 1905, the excavation for the shield chambers was finished; the erection of the shields was started at the end of that month.

TABLE 11.

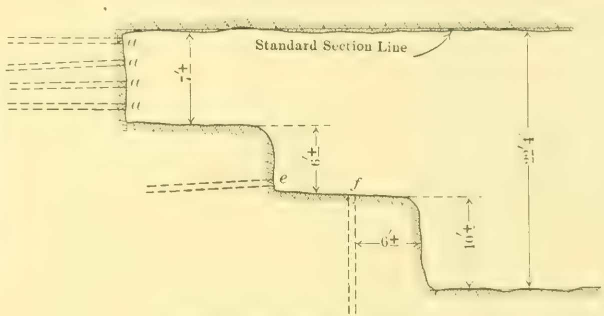
Grade.	Total No.	Rate per day.	Drilling and blasting: No.	Mucking: No.	Timbering: No.
Superintendent........	1	$7.70	½	⅛	⅜
Assistant engineer.....	1	5.80	½	⅛	⅜
Electrician	1	3.50	½	⅛	⅜
Engineer	1	3.50	....	1	....
Signalman.............	1	2.00	....	1	....
Foreman	3	4.00	1	1	1
Driller..................	5	3.00	5	....	....
Driller's helper........	5	2.00	5	....	....
Laborers...............	14	2.00	....	14	....
Timbermen............	3	3.00	....	....	3
" helpers....	4	2.00	....	....	4
Machinist..............	1	4.00	1	....	....
Blacksmith.............	2	3.50	2	....	....
" helper.......	2	2.00	2	....	....
Nipper..................	2	2.00	2	....	....
Waterboy..............	1	2.00	1	....	....
Total..........	47	....	20½	17⅜	9⅛

The general scheme of excavation is shown by Plate LXXXVII. The bench was kept 50 or 60 ft. behind the face of the heading. The powder used was 60% Forcite. The general system of drilling was as shown in Fig. 7. The average length of hole drilled per cubic yard of excavation was 2.9 ft., as against 7.70 ft. at Manhattan; and the amount of powder used was 1.96 lb. per cu. yd., as against 1.24 lb. at Manhattan. There was little timbering. A length of about 30 or 40 ft. adjoining the Weehawken shaft was timbered, and also a shattered seam of about 17 ft. in width between Stations 262 + 10 and 262 + 27.

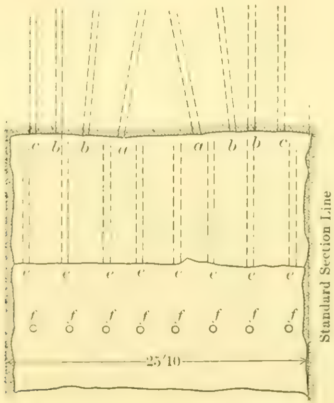
The two entirely separate tunnels gave a cross-section which was much more easily timbered than the wide flat span at Manhattan, and



TYPICAL CROSS-SECTION



LONGITUDINAL SECTION X X



PLAN OF BENCH AND HEADING

Kind of Rock Altered Sandstone and Trap in horizontal strata.
" " Dynamite — 60% Forcite, average 2 lb. per cubic yard.
Drills – (Driven by compressed air), Ingersoll-Sergeant No. 3¼ F 24.

Steel 1⅜	Diam.	2' long	has	3¼	bits
"	"	"	4' "	"	3⅛	"
"	"	"	6' "	"	3	"
"	"	"	8' "	"	2⅞	"
"	"	"	10' "	"	2¾	"

6 Cut Holes	a	10' deep	
8 Side "	b	"	"
8 " "	c	"	"
5 Top "	d	"	"
8 Lift "	e	"	"
8 Bench "	f	"	"

LAND TUNNELS
TYPICAL METHOD OF DRILLING USED IN THE WEEHAWKEN TUNNELS

FIG. 7.

the segmental timbering was amply strong without posts or other reinforcement.

Table 12 is a summary of the cost of excavating the Land Tunnels, based on actual records carefully kept throughout the work.

TABLE 12.—COST OF EXCAVATION OF LAND TUNNELS, IN DOLLARS PER CUBIC YARD.

	Manhattan.	Weehawken.	Total yardage and average cost.
Cubic yards excavated	43 289	8 311	51 600
Labor.			
Surface transport	$0.49	$0.87	$0.55
Drilling and blasting	2.37	1.55	2.24
Mucking	2.49	2.08	2.42
Timbering	0.87	0.18	0.76
Total labor	$6.22	$4.68	$5.97
Material.			
Drilling	$0.15	$0.15	$0.15
Blasting	0.21	0.21	0.21
Timber	0.39	0.20	0.36
Total material	$0.75	$0.56	$0.72
Plant running	$0.76	$0.65	$0.74
Surface labor, repairs and maintenance	0.15	0.08	0.14
Field office administration	1.05	1.18	1.07
Total field charges	$8.96	$7.15	$8.64
Chief office administration	$0.34	$0.38	$0.34
Plant depreciation	0.66	1.01	0.72
Street and building repairs	0.27	....	0.23
Total average cost per cubic yard	$10.23	$8.54	$9.93

Masonry Lining of Land Tunnels.

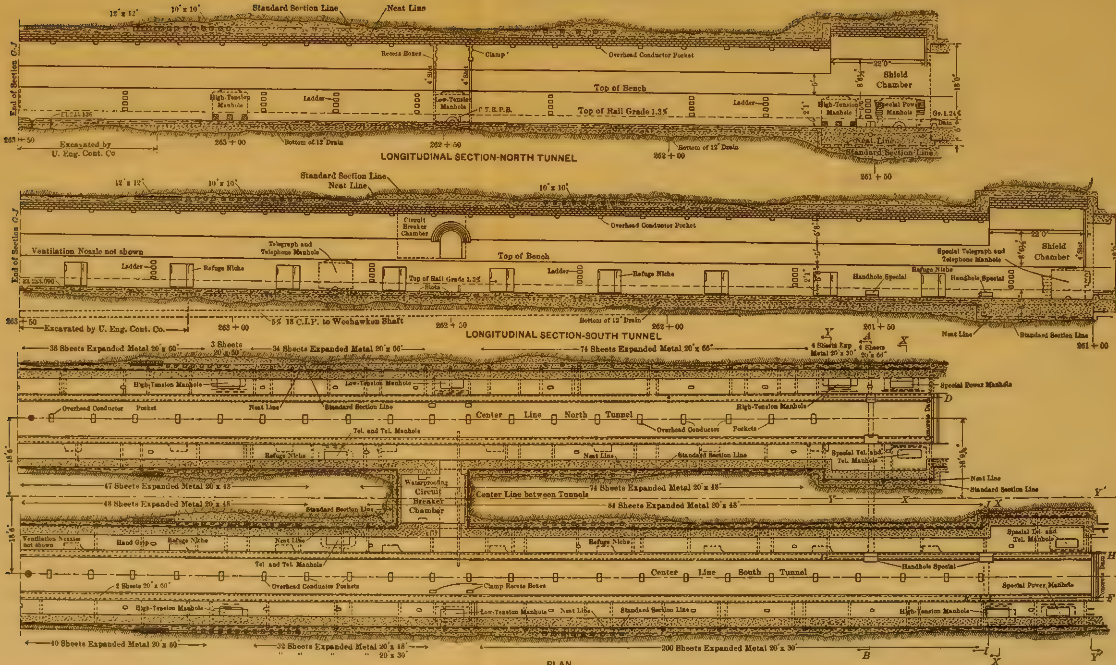
Plates LXXXVI and LXXXVIII show in detail the tunnels as they were actually built. It will be seen that in all work, except in the Gy-East contract, there was a bench at each side of each tunnel in which the cable conduits were embedded. In Gy-East the bank of ducts which came next to the middle wall was carried below subgrade, and the inner benches were omitted.

The side-walls and subgrade electric conduits were water-proofed with felt and pitch. The water-proofing was placed on the outside of the side-walls (that is, on the neat line), and the space between

PLATE LXXXVIII.
PAPERS, AM. SOC. C. E.
APRIL, 1910.
HEWETT AND BROWN ON
PENN. R. R. TUNNELS: THE NORTH RIVER TUNNELS.

WEEHAWKEN TUNNELS

PLAN AND LONGITUDINAL SECTIONS



the rock and the water-proofing was filled with concrete. This concrete was called the "Sand-Wall."

The general sequence of building the masonry lining is shown in Fig. 8. The operations were as follows:

1.—Laying concrete for the whole height of the sand-walls, and for the floor and foundations for walls and benches up to the level of the base of the conduits;

2.—Water-proofing the side-walls, and, where there was a middle trench containing subgrade conduits, laying and water-proofing these conduits;

3.—Building concrete wall for conduits to be laid against, and, where there was a middle trench, filling up with concrete between the conduits;

4.—Laying conduits;

5.—Laying concrete for benches and middle-wall;

6.—Building haunches from top of bench to springing of brick arch;

7.—Building brick arch and part of concrete back-filling;

8.—Finishing back-filling.

The whole work will be generally described under the headings of Concrete, Brickwork, Water-proofing, and Electric Conduits.

Concrete.—The number of types and the obstructions caused by the heavy posting of the timbering made it inadvisable to use built-up traveling forms at the Manhattan side, though they were used in the Weehawken Rock Tunnels.

The specifications required a facing mixture of mortar to be deposited against the forms simultaneously with the placing of the concrete. This facing mixture was dry, about 2 in. thick, and was kept separate from the concrete during the placing by a steel diaphragm. The diaphragm was removed when the concrete reached the top of each successive layer, and the facing mixture and concrete were then tamped down together. This method was at first followed and gave good results, which was indeed a foregone conclusion, as the Weehawken shaft had been built in this way. However, it was found that as good results, in the way of smooth finish, were to be obtained without the facing mixture by spading the concrete back from the forms, so that the stone was forced back and the finer portion of the

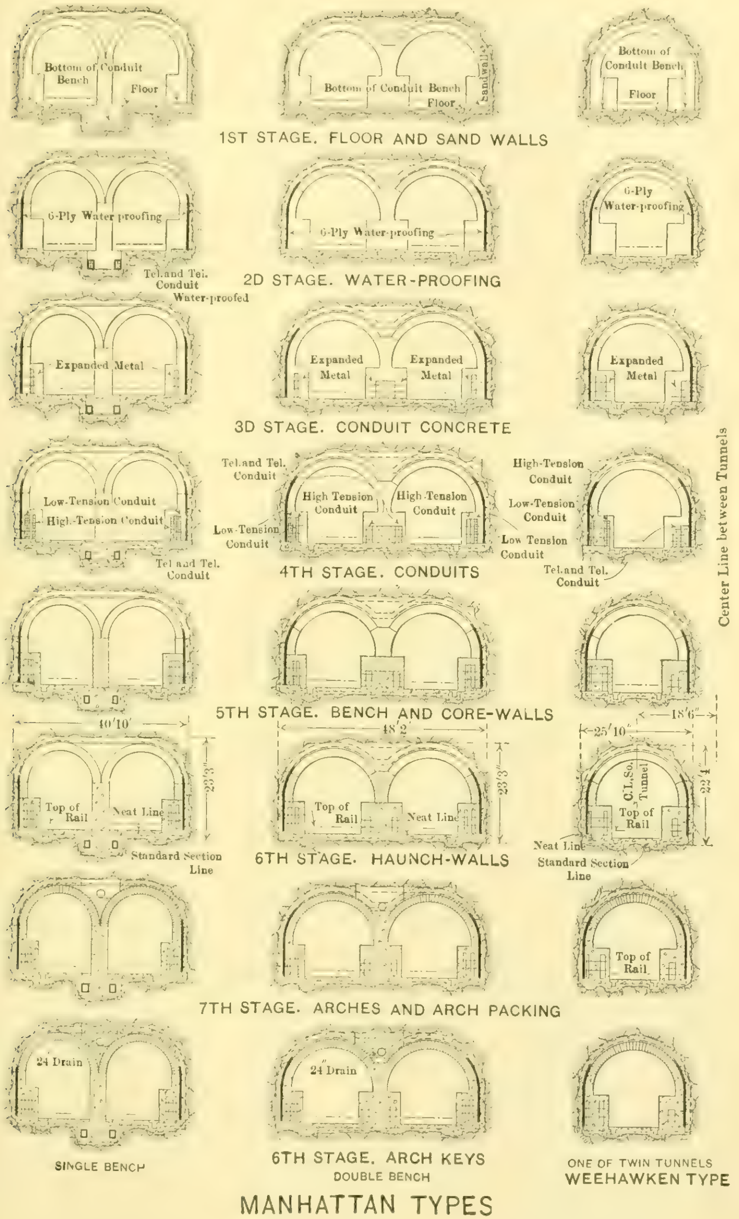
mixture came against the forms; this method was followed for the rest of the work. All corners were rounded off on a 1-in. radius by mouldings tacked to the forms. The side-bench forms were used about four times, and were carefully scraped, planed, filled at open joints, and oiled with soap grease each time they were set up. When too rough for face work they were used for sand-wall and other rough work.

The mixing was done by a No. 4 Ransome mixer, driven by 30-h.p. electric motors. The mixer at Manhattan was set on an elevated platform at the north end of the intercepting arch; that at Weehawken was placed at the entrance to the tunnels. The sand and stone were stored in bins above the mixers, and were led to the hoppers of the mixers through chutes. The hoppers were divided into two sections, which gave the correct quantities of sand and stone, respectively, for one batch. The water was measured in a small tank alongside. A "four-bag" batch was the amount mixed at one time, that is, it consisted of 4 bags of cement, $8\frac{3}{4}$ cu. ft. of sand, and $17\frac{1}{2}$ cu. ft. of broken stone, and was called a $1:2\frac{1}{2}:5$ mixture. It measured when mixed about $\frac{3}{4}$ cu. yd.

The cement was furnished to the contractor by the Railroad Company, which undertook all the purchasing from the manufacturer, as well as the sampling, testing, and storing until the contractor needed it. The Railroad Company charged the contractor \$2 a barrel for this material.

The sand was required by the specifications to be coarse, sharp, and silicious, and to contain not more than 0.5% of mica, loam, dirt, or clay. All sand was carefully tested before being used. The stone was to be a sound trap or limestone, passing a $1\frac{1}{2}$-in. mesh and being retained on $2\frac{3}{8}$-in. mesh. The contractor was allowed to use a coarser stone than this, namely, one that had passed a 2-in. and was retained on a $1\frac{1}{2}$-in. mesh.

The concrete was to be machine-mixed, except in cases of local necessity. The quantity of water used in the mixture was to be such that the concrete would quake on being deposited, but the engineer was to use his discretion on this point. Concrete was to be deposited in such a manner that the aggregates would not separate. It was to be laid in layers, not exceeding 9 in. in thickness, and thoroughly rammed. When placing was suspended, a joint was to be formed in



Bottom of Conduit Bench
Floor
Bottom of Conduit Bench
Floor
Sand walls
Bottom of Conduit Bench
Floor
1ST STAGE. FLOOR AND SAND WALLS
6-Ply Water-proofing
Tel. and Tel. Conduit Water-proofed
6-Ply Water-proofing
6-Ply Water-proofing
2D STAGE. WATER-PROOFING
Expanded Metal
Expanded Metal
Expanded Metal
Expanded Metal
3D STAGE. CONDUIT CONCRETE
Low-Tension Conduit
High-Tension Conduit
Tel and Tel. Conduit
Tel. and Tel. Conduit
High Tension Conduit
High Tension Conduit
Low-Tension Conduit
Low Tension Conduit
High-Tension Conduit
Low-Tension Conduit
Tel. and Tel. Conduit
4TH STAGE. CONDUITS
Center Line between Tunnels
5TH STAGE. BENCH AND CORE-WALLS
40'10'
23'3"
Top of Rail
Neat Line
Standard Section Line
48'2"
23'3"
Top of Rail
Neat Line
25'10"
18'6"
C.L.So. Tunnel
23'4"
Top of Rail
Neat Line
Standard Section Line
6TH STAGE. HAUNCH-WALLS
Top of Rail
7TH STAGE. ARCHES AND ARCH PACKING
24 Drain
24" Drain
SINGLE BENCH
6TH STAGE. ARCH KEYS
DOUBLE BENCH
ONE OF TWIN TUNNELS
WEEHAWKEN TYPE
MANHATTAN TYPES

FIG. 8.

a manner satisfactory to the engineer. Before depositing fresh concrete, the entire surface on which it was to be laid was to be cleaned, washed and brushed, and slushed over with neat cement grout. Concrete which had begun to set was not to be used, and retempering was not to be allowed.

The forms were to be substantial and hold their shape until the concrete had set. The face forms were to be of matched and dressed planking, finished to true lines and surfaces; adequate measures were to be taken to prevent concrete from adhering to the forms. Warped or distorted forms were to be replaced. Plastering the face was not allowed. Rock surfaces were to be thoroughly washed and cleaned before the concrete was deposited.

These specifications were followed quite closely.

A typical working gang, as divided among the various operations, is shown below:

Superintendence.

½ Superintendent	@ $250	per month
½ Assistant engineer	" 150	" "
1 Assistant superintendent	" 150	" "

Surface Transport.

1 Foreman	@ $2.50	per day
1 Engineer	" 3.00	" "
1 Signalman	" 2.00	" "
16 Laborers	" 1.75	" "
3 Teams	" 7.50	" "

Laying.

1 Foreman	@ $4.00	per day
8 Laborers	" 2.00	" "

Forms.

1 Foreman	@ $4.50	per day
4 Carpenters	" 3.25	" "
5 Helpers	" 2.25	" "

Tunnel Transport.

¼ Foreman	@ $3.25	per day
¼ Engineer	" 3.00	" "
¼ Signalman	" 2.00	" "
4 Laborers	" 1.75	" "

Mixers.

¼ Foreman	@	$3.25	per	day
2 Laborers	"	1.75	"	"

The superintendent and assistant engineer looked after the brick-work and other work as well as the concrete. The surface transport gang handled all the materials on the surface, including the fetching of the cement from the cement warehouses.

The tunnel transport gang handled all materials in the tunnel, but, when the haul became too long, the gang was reinforced with laborers from the laying gang. Of the laying gang, two generally did the spading, two the spreading and tamping, and the remaining force dumped the concrete. The general cost of this part of the work is shown in Table 13.

The figures in Table 13 include the various items built into the concrete and some that are certificate extras in connection with the concrete, such as drains, ironwork and iron materials, rods and bars, expanded metal, doors, frames and fittings, etc.

Water-proofing.—According to the specifications, the water-proofing was to consist of seven layers of pitch and six layers of felt on the side-walls and a ½-in. layer of mastic, composed of coal-tar and Portland cement, to be plastered over the outside of the arches.

By the time the work was in hand, some distrust had arisen as to the efficiency of this mastic coating, and a great deal of study was devoted to the problem of how to apply a felt and pitch water-proofing to the arches. The difficulty was that there was no room between the rock and the arch or between the timber and the arch (as the case might be) in which to work. Several ingenious schemes of putting the felt on in layers, or in small pieces like shingles, were proposed and discussed, and a full-sized model of the tunnel arch was even built on which to try experiments, but it was finally decided to overcome the difficulty by leaving out the arch water-proofing altogether, and simply building in pipes for grouting through under pressure, in case it was found that the arch was wet.

As to the arch built through the length excavated by cut-and-cover on the New York side, it was resolved to water-proof that with felt and pitch exactly as the side-walls were done, the spandrel filling between the arches being raised in a slight ridge along the concrete line between tunnels in order to throw the water over to

TABLE 13.—COST OF CONCRETE IN LAND TUNNELS, IN DOLLARS PER CUBIC YARD.

	Manhattan.	Weehawken.	Total yardage.
Cubic yards placed	14 706½	3 723	18 429½
LABOR.	**Average Cost per Cubic Yard.**		
Surface transport	$0.31	$1.43	$0.54
Superintendence and general labor at point of work	0.31	1.31	0.51
Mixing	0.52	0.56	0.53
Laying	1.38	1.45	1.39
Tunnel transport	1.30	1.47	1.34
Cleaning	0.21	....	0.17
Forms: erecting and removal	1.58	1.51	1.56
Total labor	$5.61	$7.73	$6.04
MATERIAL.			
Cement	$2.30	$2.22	$2.28
Sand	0.34	0.40	0.36
Stone	0.91	0.61	0.85
Lumber for forms	0.47	0.45	0.47
Sundry tunnel supplies	0.16	0.17	0.16
Total materials	$4.18	$3.85	$4.12
Plant running	$0.44	$0.44	$0.44
Surface labor, repairs and maintenance	0.25	1.24	0.44
Field office administration	0.50	1.72	0.75
Total field charges	$10.98	$14.98	$11.79
Plant depreciation	$0.62	$1.57	$0.81
Chief office administration	0.24	0.31	0.25
Total average cost per cubic yard	$11.84	$16.86	$12.85

Cost of Miscellaneous Items in Concrete.

	Manhattan.	Weehawken.	Average.
Cubic yards	14 706½	3 723	18 429½
Amount, in dollars	$6 184.83	$1 756.79	$7 941.62
Unit cost	0.42	0.47	0.43

the sides. The portions of arch not water-proofed were rather wet, and grouting with a 1:1 mixture was done, but only with the effect of stopping large local leaks and distributing a general dampness over the whole surface of the arch.

The 24-ft. 6-in. tunnel adjoining the Terminal Station-West was water-proofed by a surface-rendering method which, up to the present time, has been satisfactory. Generally speaking, the arches of the Land Tunnels, though not dripping with water, are the dampest parts of the whole structure from Tenth Avenue to Weehawken, and it would seem as if some form of water-proofing over these arches would have been a distinct advantage.

There was no difficulty in applying the water-proofing on the side-walls, after a little experience had been gained as to the best methods. The specifications required the sand-wall to be covered with alternate layers of coal-tar pitch and felt, seven layers of the former and six layers of the latter, the felt to be of Hydrex brand or other equally satisfactory to the engineer. The pitch was to be straight-run, coal-tar pitch which would soften at 60° Fahr., and melt at 100° Fahr., being a grade in which distillate oils, distilled from it, should have a specified gravity of 1.105. The pitch was to be mopped on the surface to a uniform thickness of $\frac{1}{16}$ in., and a covering of felt, previously mopped with pitch, was to be applied immediately. The sheets were to lap not less than 4 in. on cross-joints and 12 in. on longitudinal joints, and had to adhere firmly to the pitch-covered surface. This layer was then to be mopped, and another layer placed, and so on until all the layers were in place. This water-proofing was to extend from the bottom of the cable conduits to the springing of the brick arch. Where sub-track conduits were used, these were to be surrounded with their own water-proofing. The work was carried out as specified; the sand-walls were not rendered, but were built smooth enough to apply the water-proofing directly to them. They were dried with gasoline torches before the application of the pitch, and in very wet sections grooves were cut to lead the water away.

The first attempts were with the felt laid in horizontal strips. This ended very disastrously, as the pitch could not sustain the weight of the felt, and the whole arrangement slipped down the wall. The felt was then laid vertically, being tacked to a piece of horizontal scantling at the top of the sand-wall and also held by a row of planks

braced against it at about half its height. A layer of porous brick was laid as a drain along the base of the water-proofing, covered by a single layer of felt to prevent it from becoming choked with concrete.

The water-proofing of the sub-track conduits was troublesome, as the numerous layers and the necessity for preserving the proper laps in both directions between adjacent layers made the whole thing a kind of Chinese puzzle. Various modifications, to suit local conditions, were made from time to time. Conduits outside the general outline of the tunnel are difficult to excavate, to lay, and to water-proof, and should be avoided wherever possible.

The usual force in water-proofing consisted of a foreman, at $3.50 per day, and nine laborers at $1.75 per day. These men not only laid the water-proofing, but transported the materials, heated the pitch, and cut up the rolls of felt. In general, two men transported material, one tended the heater, and the other six worked in pairs, two preparing the surface of the concrete sand-wall, two laying pitch, and two laying felt.

The cost of the water-proofing operation was about as shown in Table 14.

TABLE 14.—Cost of Water-Proofing, in Dollars per Square Foot.

	Manhattan.	Weehawken.	Total.
Square feet covered	47 042	13 964	60 736
	Average cost per square foot.		
Labor	$0.07	$0.07	$0.07
Material	0.12	0.09	0.11
Total field charges	$0.19	$0.16	$0.18
Chief office and plant depreciation	0.01	0.03	0.02
Total average cost	$0.20	$0.19	$0.20

Brickwork in Arches.—Owing to the heavy timbering, the brick-work at Manhattan was interfered with to a considerable extent, and the gang was always kept at work at two or more places. The work was carried up to a point where it was necessary to back-fill, or prop or cut away encroaching timbers, and then the men were moved to another place while this was being done.

The centers were set up in sets of seven, spaced 4 ft. apart. Two

14-ft. lengths of 3 by 4-in. yellow pine lagging were used with each set of ribs, with 24 by 8-in. block lagging in the crown.

All centers were set $\frac{1}{4}$ in. high, to allow for settlement, except in the 24-ft. 6-in. span, in which they were set $\frac{1}{2}$ in. high. This proved ample, the average settlement of the ribs being 0.01 ft. and of the masonry, 0.003 ft. In the 24-ft. 6-in. span the ribs were strengthened with 6 by 6-in. blocking and 12 by 12-in. posts to subgrade. Great trouble was here encountered with encroaching timbering, due to the settlement of the wide flat span. Grout pipes were built in, as previously mentioned.

Each mason laid an average of 0.535 cu. yd. of brickwork per hour, or 4.28 cu. yd. per day. The number of bricks laid per mason per hour was 218, or 1 744 per day.

The bricks were of the best quality of vitrified paving brick, and were obtained from the Jamestown Brick Company, of Jamestown, N. Y. The average size was $8\frac{3}{4}$ by $3\frac{15}{16}$ by $2\frac{7}{16}$ in.; the average number per cubic yard of masonry was 408, the arches being from 19 ft. to 24 ft. 6 in. in span and from 22 to 27 in. thick. The joints were $\frac{3}{16}$ in. at the face and averaged $\frac{9}{16}$ in. through the arch.

The proportions for mortar were 1 of cement and $2\frac{1}{2}$ of sand. One cubic yard of masonry was composed of 73.5% brick and 26.5% mortar. The volume of the ingredients in a four-bag batch was 12.12 cu. ft., and the resulting mixture was 9.54 cu. ft. The number of barrels of cement was 0.915 per cu. yd. of masonry, and about 17.7% of the mortar made was wasted. The average force employed was:

Laying.

1 Foreman	@	$8.00	per	day
4 Layers	"	6.00	"	"
8 Tenders	"	2.00	"	"
2 Mixers	"	2.00	"	"

Forms.

1 Foreman	@	$4.50	per	day
4 Carpenters	"	3.50	"	"
5 Helpers	"	2.25	"	"

Transport.

$\frac{1}{4}$ Hoist engineer	@	$3.00	per	day
$\frac{1}{4}$ Signalman	"	2.00	"	"
4 Laborers	"	2.00	"	"

For materials, the following prices prevailed:

Cement, $2.00 per bbl.,

Sand, $0.90 to $1.00 per cu. yd.,

Brick, $16.00 per thousand, delivered at yard,

Centers, $26.00 each,

Lagging, $45.00 per 1 000 ft. B. M.

The cost of the brickwork is given in Table 15.

TABLE 15.—COST OF BRICKWORK.

	Manhattan.	Weehawken.	Total.
Cubic yards placed	4 137	790	4 927
LABOR.	Average Cost per Cubic Yard.		
Surface transport	$0.35	$1.19	$0.48
Superintendent and general labor at point of work	0.17	0.04	0.16
Laying and mixing	2.58	3.20	2.60
Forms: erection and removal	2.62	0.32	2.25
Tunnel transport	1.19	1.12	1.18
Total labor	$6.91	$5.87	$6.75
MATERIAL.			
Brick	$6.56	$6.56	$6.56
Cement	1.76	1.75	1.76
Sand	0.20	0.28	0.22
Forms	0.92	0.98	0.93
Overhead conductor pockets	0.15	0.09	0.13
Total material	$9.59	$9.66	$9.60
Plant running	$0.55	$0.30	$0.51
Surface labor, repairs and maintenance	0.36	1.30	0.51
Field office administration	0.55	0.88	0.60
Total field charges	$17.96	$18.01	$17.97
Chief office administration	$0.60	$0.66	$0.61
Plant depreciation	0.35	0.64	0.39
Total average cost per cubic yard	$18.91	$19.31	$18.97

In Table 16 the cost of grout is expressed in terms of barrels of cement used, because that was in the schedule of prices attached to the contract as the unit of payment for grout.

TABLE 16.—Cost of Grout Over Arches in Land Tunnels.
Cost, in Dollars per Barrel of Cement Used.

	Manhattan. (Gy-East only.)	Weehawken.	Total.
Barrels used	3 000½	261½	3 262
	Average Cost per Barrel of Cement Used.		
Labor	$0.55	$0.46	$0.53
Material	2.30	2.25	2.28
Field office administration	0.08	0.06	0.08
Plant and supplies	0.10	0.07	0.09
Total field charges	$3.03	$2.84	$2.98
Chief office and plant depreciation	0.21	0.22	0.22
Total average cost	$3.24	$3.06	$3.20

Vitrified Earthenware Conduits for Electric Cables.—The general drawings will show how the ducts were arranged, and that manholes were provided at intervals. They were water-proofed, in the case of those embedded in the bench, by the general water-proofing of the tunnels, which was carried down to the level of the bottom of the banks of ducts; and in the case of those below subgrade, by a special water-proofing of felt and pitch wrapped around the ducts themselves.

The portion of wall in front of the ducts was bonded to that behind by bonds, mostly of expanded metal, passing between the ducts. Examples of the bonding will be seen in the drawings.

The joints between successive lengths of 4-way and 2-way ducts were wrapped with two thicknesses of cotton duck, 6 in. wide, those of single-way ducts were not wrapped, but plastered with cement mortar. The ducts were laid on beds of mortar, and were made to break joints at top and bottom, and side to side with the adjacent ducts. They were laid with a wooden mandrel; a square leather washer at the near end acted as a cleanser when the mandrel was pulled through.

The specifications required the ducts to be laid at the same time as the concrete and be carried up with it, but this was found to be a very awkward operation, as the tamping of the concrete and the

walking of men disturbed the ducts, especially as the bonds lay across them. It was resolved, therefore, to build the portion of the wall behind the ducts first, with the bonds embedded in it at the proper heights and projecting from it, then to lay up the banks of ducts against this wall, bending the bonds down as they were reached, and finally, after all the ducts were in, to lay the concrete in front of and over the top of the ducts. Several detailed modifications of this general scheme were followed at one time or another when necessary or advisable.

The laying of ducts below subgrade was not complicated by the presence of bonds, the water-proofing caused the trouble here, as before described.

The specifications called for a final rodding after completion. A group of the apparatus used in this process is shown in Fig. 1, Plate LXXXIX; the various parts are identified by the following key:

KEY TO FIG. 1, PLATE LXXXIX.

1.—4-way duct, for telephone and telegraph cables,
2.—2-way duct, for telephone and telegraph cables,
3.—1-way duct, for high- and low-tension cables,
4.—Plug for closing open ends of ducts,
5.—Plug for closing open ends of ducts in position,
6, 7, and 8.—Cutters for removing obstructions,
9.—Hedgehog cutter for removing grout in ducts,
10.—Rodding mandrel for multiple ducts,
11.—Laying mandrel,
12.—Rodding mandrel, with jar-link attached,
13.—Laying mandrel,
14 and 15.—Rubber-disk cleaners, used after final rodding,
16 and 17.—Sectional wooden rods used for rodding,
18.—Section of iron rods used for rodding.
19.—Jar-link,
20.—Cotton duck for wrapping joints of multiple ducts,
21.—Hook for pulling forward laying mandrel,
22.—Top view of trap for recovering lost or broken rods left in ducts.

Ordinary $\frac{3}{4}$-in. gas pipe was used for the rod, and a cutter with rectangular cross-section and rounded corners was run through ahead of the mandrel: following the cutter came a scraper consisting of

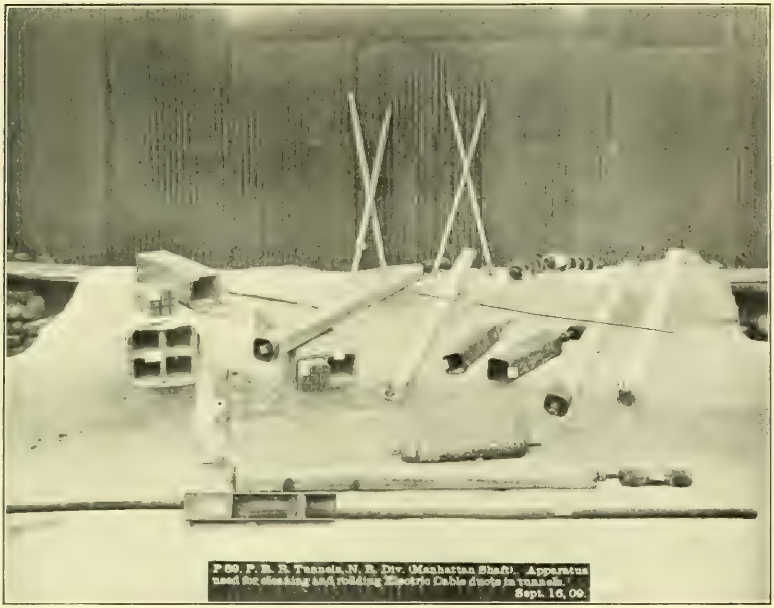

P 89. P. R. R. Tunnels, N. R. Div. (Manhattan Shaft). Apparatus
used for cleaning and rodding Electric Cable ducts in tunnels.
Sept. 16, 09.

FIG. 1.


A 39. P. R. R. Tunnels, N. R. Div. Sect. Gy. Showing
Shield, (South Manhattan) in Hudson River Silt with
one door of Shield open.
Aug. 24, 06.

FIG. 2.

several square leather washers, of the size of the ducts, spaced at intervals on a short rod. The mandrel itself was next put through, three or four men being used on the rods. All the ducts in a bank were thus rodded from manhole to manhole. When a duct was rodded it was plugged at each end with a wooden plug. A solid wooden paraffined plug was used at first, but afterward an expansion plug was used.

Very little trouble was met in rodding the power conduits, except for a few misplaced ducts, or a small mound of mortar or a laying mandrel left in. At such points a cut was made in the concrete and the duct replaced.

In the subgrade telephone and telegraph ducts east of the Manhattan Shaft, much trouble was caused by grout in the ducts. The mandrel and cutters were deflected and broke through the web of the ducts rather than remove this hard grout. Trenches had to be cut from the floor to the top of the water-proofing, the latter was then cut and folded back, and the ducts replaced. To do this, a number of ducts had to be taken out to replace the broken ones and get the proper laps. The water-proofing was then patched and the concrete replaced. This grout had not penetrated the water-proofing, but had got in through the ends of the ducts where they had not been properly plugged and protected. The duct gang, both for laying and rodding, generally consisted of

1 Foreman, at \$3.50 per day,
and 9 laborers, at \$1.75 per day.

When laying: 4 men were laying, 2 men mixing and carrying mortar, and 3 were transporting material. When rodding: 4 men were rodding, 2 men at adjacent manholes were connecting and disconnecting cutters and mandrels, 1 was joining up rods, and 2 men assisting generally.

The cost of this work is shown in Table 17.

Transportation and Disposal.

The track on the surface and in the tunnels was of 20-lb. rails on a 2-ft. gauge.

The excavation was handled in scale-boxes carried on flat cars, and the concrete in $1\frac{1}{4}$-cu. yd. mining cars dumping either at the side or end.

TABLE 17.—COST OF CONDUIT WORK.

	Manhattan.	Weehawken.	Total.
Duct feet	115 962	35 155	151 117
	Average Cost per Duct Foot.		
Labor	$0.035	$0.032	$0.034
Material	0.043	0.052	0.045
Total field charges	0.078	0.084	0.079
Chief office and plant depreciation	0.005	0.008	0.006
Total average cost	$0.083	$0.092	$0.085

When the haulage was up grade, 6 by 6-in. Lidgerwood hoisting engines, with 10-in. single friction drums, and driven by compressed air from the high-pressure lines, were used. Down grade, cars were moved and controlled by hand.

The muck which came through the shaft at Manhattan was dumped into hopper bins on the surface and thence loaded into trucks at convenience. At the open cut, the muck was dumped into trucks direct. The trucking was sublet by the contractor to a sub-contractor, who provided trucks, teams, and trimmers at the pier. At Weehawken, arrangements were made with the Erie Railroad which undertook to take muck which was needed as fill. The tunnel cars, therefore, were dumped directly on flat cars which were brought up to a roughly made platform near the shaft.

The hoisting at Manhattan was by derrick at Tenth Avenue and the open cut, and by the elevator at the Manhattan Shaft. At Weehawken, all hoisting was done by the elevator in the shaft.

The sand and stone were received at the wharves by scows. At Manhattan, these materials were unloaded on trucks by an overhead traveler, and teamed to the shaft, where they were unloaded by derricks into the bins. At Weehawken, they were unloaded by an orange-peel grab bucket, loaded into cars on the overhead trestle, transported in these to the top of the shaft, and discharged into the bins.

The cement at Manhattan was trucked from the Company's warehouse, at Eleventh Avenue and 38th Street, to the shaft, where it was

put into a supplementary storage shed at the top of the shaft, whence it was removed to the mixer by the elevator when needed. At Weehawken, it was taken on flat cars directly from the warehouse to the mixer.

Lighting.

Temporarily and for a short time at the start, kerosene flares were used for light until replaced by electric lights, the current for which was furnished by the contractor's generators, which have been described under the head of "Power Plant."

The lamps used along the track were of 16 c.p., and were protected by wire screens; these were single, but, wherever work was going on, groups of four or five, provided with reflectors, were used.

Pumping.

Two pumps were installed at the Manhattan Shaft. They had to handle the water, not only from the rock tunnels, but also from those under the river. One was a Deane compound duplex pump, having a capacity of 500 gal. per min., the other, a Blake pump, of 150 gal. per min. They were first driven by steam direct from the power-house, but compressed air was used later. When the power-house was shut down, an electrically-driven centrifugal pump was used. This was driven by a General Electric shunt-wound motor, Type C-07½, with a speed of 1 250 rev. per min. at 250 volts and 37.5 amperes (10 h.p.) when open, and 22.9 amperes (6 h.p.) when closed, and had a capacity of 450 gal. per min. To send the water to the shaft sump during the construction, small compressed-air Cameron pumps, of about 140 gal. per min., were used.

At the Weehawken shaft two pumps were used; these dealt with the water from the Bergen Hill Tunnels as well as that from the Weehawken Tunnels. At first a Worthington duplex pump having a capacity of about 500 gal. per min. was used. Later, this was replaced by a General Electric shunt-wound motor, Type O-15, with a speed of 925 rev. per min. at 230 volts and 74 amperes (20 h.p.) when open, and 38.5 amperes (10 h.p.) when closed. Its capacity was 240 gal. per min. During the progress of the construction, the water was pumped from the working face to the shaft by small Cameron pumps similar to those used at Manhattan. When the work was finished,

a subgrade reversed-grade drain carried the water to the shaft sump by gravity.

The work in the Manhattan Land Tunnels was practically finished by May 1st, 1908, though the ventilating arrangements and overhead platform in the intercepting arch were not put in until after the River Tunnel concrete was completed, so that the work was not finished until September, 1909.

The Weehawken Land Tunnels work was finished in July, 1907, but the benches and ventilating arrangements in the Weehawken Shaft were not put in until after the completion of the Bergen Hill Tunnels, and so were not finished until August, 1909.

The reinforced concrete wall around the Weehawken Shaft, together with the stairs from the bench level of the shaft to the surface, was let as a separate contract; the work was started on September 15th, 1909, and finished by the end of December, 1909.

River Tunnels.

The River Tunnel work, from some points of view, has the most interest. It is interesting because it is the first main line crossing of the formidable obstacle of the Hudson River, and also by reason of the long and anxiously discussed point as to whether, in view of the preceding experiences and failures to construct tunnels under that river, foundations were needed under these tunnels to keep them from changing in elevation under the action of heavy traffic.

The River Tunnels here described start on the east side of the shield chambers on the New York side and end at the east side of the shield chambers on the New Jersey side. They thus include the New York and exclude the New Jersey shield chambers, the reason for such discrimination being that the New York shield chambers are lined with cast iron while those on the New Jersey side are of the typical rock section type, as already described. The design of the tunnels and their accessories will be first described, then will come the construction of the tunnels as far as the completion of the metal lining, followed by a description of the concrete lining and completion of the work.

Design of Metal Lining.

New York Shield Chambers.—The shield chambers may be seen on Plate LXXXVI, previously referred to, which shows the junction of the iron-lined tunnels and the shield chambers. They consist of two

iron-lined pieces of tunnel placed side by side, with semi-circular arches and straight side-walls. The segments of the arch are made to break joint with one another by making the side-wall or column castings of two different heights, as shown in Fig. 9. The length of each ring is 18 in.

The reason for the adoption of this type of construction was the necessity for keeping the width of the permanent structure within the 60-ft. width of the street. The length of this twin structure is 28.5 ft., and the weight of the metal in it is as follows:

19 long-column arch rings at 22 802 lb.	433 238 lb.
19 short-column arch rings at 23 028 lb.	437 532 "
Total weight	870 770 lb.

General Type of River Tunnel Lining.—The main ruling type adopted for the tunnels under the Hudson River, and in the soft water-bearing ground for some distance on the shoreward side of the river lines, consists of two parallel metal-lined tunnels, circular in cross-section, each tunnel being 23 ft. outside diameter, and the two tunnels 37 ft. apart from center to center, as shown on Fig. 10. The metal lining is of cast iron (except for a few short lengths of cast steel) and of the usual segmental type, consisting of "Rings" of iron, each ring being 2 ft. 6 in. in length, and divided by radial joints into eleven segments, or "Plates," with one "Key," or closing segment, having joints not radial but narrower at the outside circumference of the metal lining than at the inside. The whole structure is joined, segment to segment, and ring to ring, by mild-steel bolts passing through bolt holes in flanges of all four faces of each segment. The joints between the segments are made water-tight by a caulking of sal-ammoniac and iron borings driven into grooves formed for the purpose on the inner edges of the flanges. The clearances between the bolts and the bolt holes are also made water-tight by using grummets or rings of yarn smeared with red lead, having a snug fit over the shank of the bolt and placed below the washer on either end of each bolt. When passing through ground more or less self-sustaining, the space outside the iron lining (formed by the excavation being necessarily rather larger than the external diameter of the lining itself) was filled with grout of 1:1 Portland cement and sand forced by air

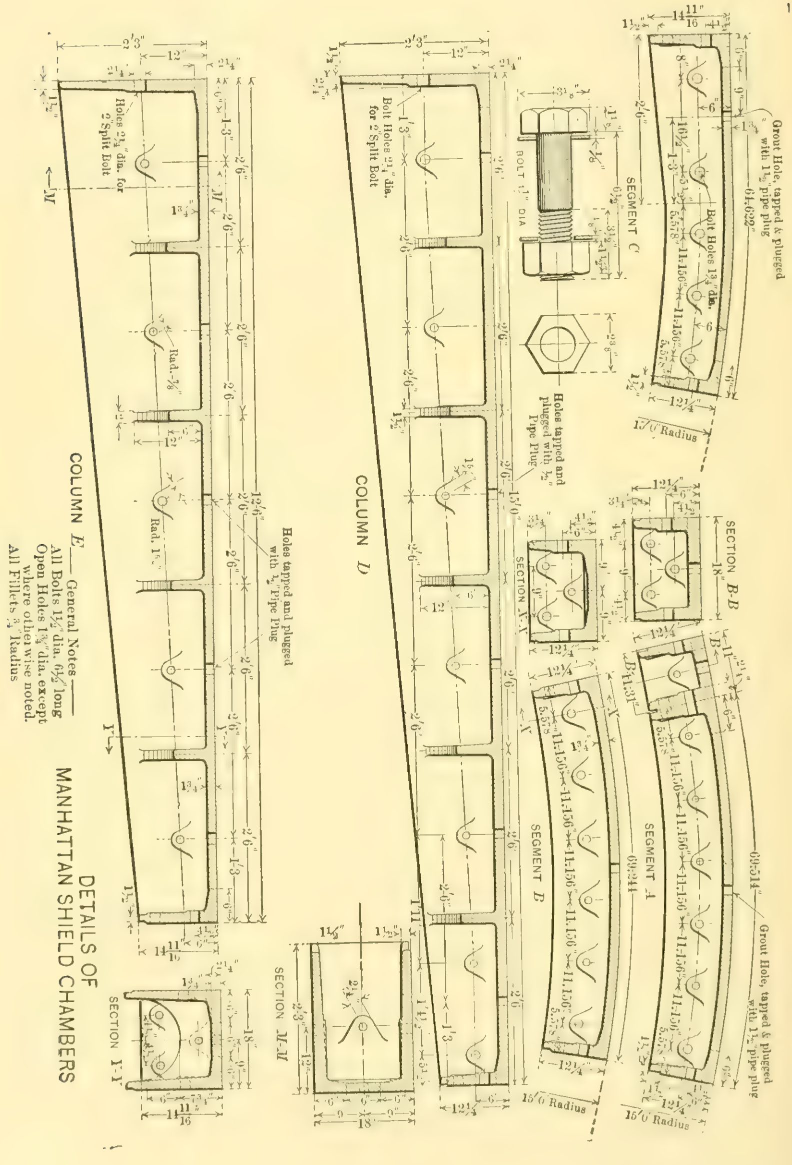


FIG. 9

DETAILS OF MANHATTAN SHIELD CHAMBERS

pressure through grout holes in each segment. These holes were tapped, and were closed with a screw plug before and after grouting.

Having thus stated in a general way the main ruling features of the design, a detailed description of the various modifications of the ruling type will be given.

TYPICAL CROSS-SECTION OF RULING DESIGN OF METAL-LINED SHIELD-DRIVEN TUNNELS

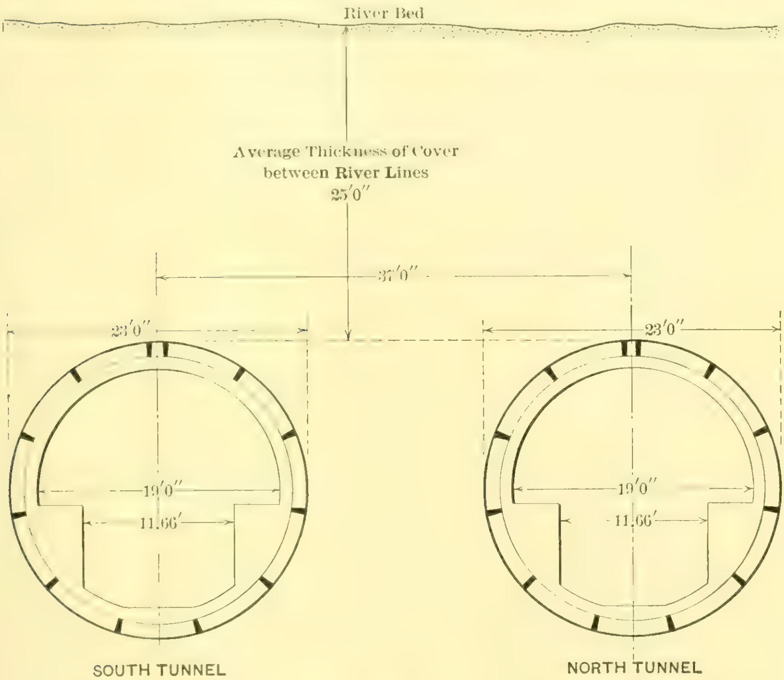


Fig. 10.

The two main divisions of the iron lining are the "ordinary" or lighter type and the heavy type. The details of the ordinary iron are shown in Fig. 11, which shows all types of lining. It was on this design that the contract was let, and it was originally intended that this should be the only type of iron used. The dimensions of the iron are clearly shown on the drawing, and it will be seen that the external diameter is 23 ft., the interior diameter, 21 ft. 2 in., the length of each ring, 2 ft. 6 in., and the thickness of the iron skin or web, 1½ in. The bolt holes in the circumferential flanges are evenly spaced through the

circle, so that adjacent rings may be bolted together in any relative position as regards the radial joints, and, as a matter of fact, in the erection of the tunnel lining, all the rings "break joint," with the exception of those at the bore segments, as will be described later. This type of iron, when the original type was modified, came to be known as the ordinary pocketless iron; that is, the weight is of the ordinary or lighter type, in contradistinction to the heavier one, which later supplanted it, and the caulking groove runs along the edges of the flanges and does not form pockets around the bolt holes, as did the groove in a later type.

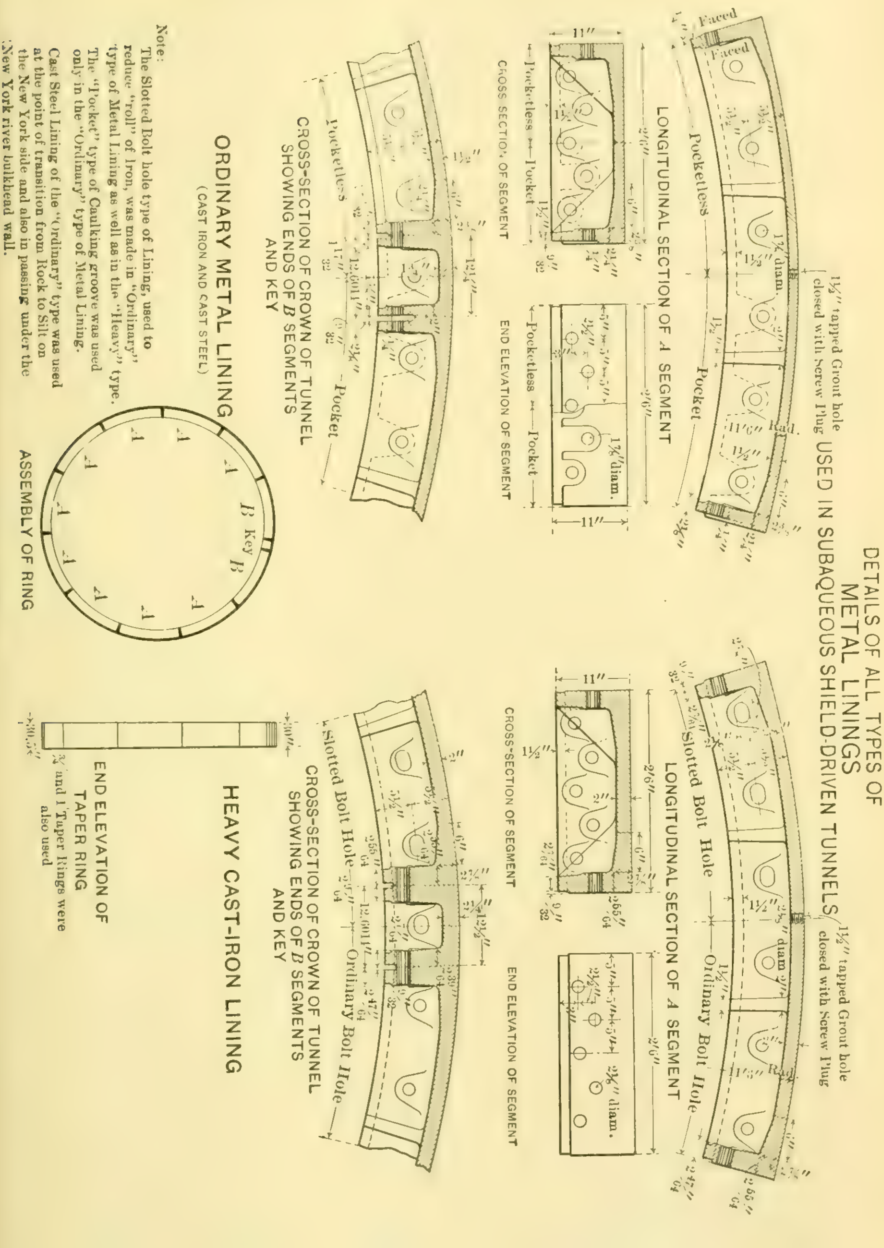
Each ring is made up of eleven segments and a key piece. Of these, nine have radial joints at both ends, and are called "*A*" segments; two, called "*B*" segments, have a radial joint at one end and a non-radial joint at the other. The non-radial joint is placed next to the key, which is 12.25 in. wide at the outside circumference of the iron and 12.50 in. wide at the inside.

The web is not of uniform thickness. The middle part of each *A* and *B* segment is $1\frac{1}{2}$ in. thick; at the distance of 6 in. from the root of each flange, the thickness of web begins to increase, so that at the root it is $2\frac{3}{8}$ in. thick. The web of the key plate is $1\frac{3}{4}$ in. thick.

The bolts are of mild steel, and are $1\frac{1}{2}$ in. in diameter; there are 67 in one circumferential joint and 5 in each radial joint. As there are 12 such radial joints, there are altogether 60 bolts in the cross-joints, making a total of 127 bolts per ring.

This original type of ordinary iron was modified for a special purpose as follows: It was known that for some distance on either side of the river, and especially at Weehawken, the tunnels would pass through a gravel formation, rather open, and containing a heavy head of water. It was thought that, by carrying the caulking groove around the bolt holes, it would be possible to make them more waterproof than by the simple use of the red-leaded grummets. Hence the "Pocket Iron" was adopted for this situation, the name being derived from the pocket-like recess which the caulking groove formed when extended around the bolt hole. The details of this lining are shown on Fig. 11, and the iron (except for the pockets) is exactly like the pocketless type.

On the New York side, in both North and South Tunnels, two short lengths were built with cast-steel lining. This was done where



DETAILS OF ALL TYPES OF METAL LININGS USED IN SUBAQUEOUS SHIELD-DRIVEN TUNNELS
1½″ tapped Grout hole closed with Screw Plug
Faced
Pocketless
Pocket
LONGITUDINAL SECTION OF A SEGMENT
CROSS SECTION OF SEGMENT
END ELEVATION OF SEGMENT
1⅞″ diam.
CROSS-SECTION OF CROWN OF TUNNEL SHOWING ENDS OF B SEGMENTS AND KEY
ORDINARY METAL LINING
(CAST IRON AND CAST STEEL)
Note:
The Slotted Bolt hole type of Lining, used to reduce "roll" of Iron, was made in "Ordinary" type of Metal Lining as well as in the "Heavy" type.
The "Pocket" type of Caulking groove was used only in the "Ordinary" type of Metal Lining.
Cast Steel Lining of the "Ordinary" type was used at the point of transition from Rock to Silt on the New York side and also in passing under the New York river bulkhead wall.
ASSEMBLY OF RING
Key
Slotted Bolt Hole
Ordinary Bolt Hole
HEAVY CAST-IRON LINING
END ELEVATION OF TAPER RING
¾ and 1″ Taper Rings were also used

FIG. 11.

unusual stresses were expected to come on the lining, namely, at the point where the invert passed from firm ground to soft, and also where the tunnels passed under the heavy river bulkhead wall.

The design was precisely the same as for the ordinary pocketless iron, and Fig. 11 shows the details. After the tunnels had entered into the actual under-river portion, several phenomena (which will be described later) led to the fear that the tunnels, being lighter than the semi-liquid mud they displaced, might be subject to a buoyant action, and therefore a heavier type of lining was designed. The length of ring, number of bolts, etc., were just the same as for the lighter iron, but the thickness of the web was increased from 1½ to 2 in., the thickness of the flanges was proportionately increased, and the diameter of the bolts was increased from 1½ to 1¾ in. This iron was all of the pocketless type, shown in Fig. 11. Table 18 gives the weights of the various types of lining.

TABLE 18.—Weights of Tunnel Lining, Diameter and Weights of Bolts, etc.

Reference No.	Type of Lining.	Weight of one "A" Segment, in pounds.	Weight of one "B" Segment, in pounds.	Weight of one key, in pounds.	Weight of one complete ring, in pounds.	Diameter of bolts, in inches.	Weight of 1 bolt, nut, and 2 washers, in pounds.	Weight of bolts, nuts, and washers per ring, in pounds.	Total weight of one ring segment and bolts, in pounds.
1	Ordinary cast iron without caulking pockets..	2 063	2 068	480	23 183	1½	6.62	840.7	24 024
2	Ordinary cast iron with caulking pockets.......	2 038	2 043	469	22 897	1½	6.62	840.7	23 738
3	Ordinary cast steel without caulking pockets..	2 247	2 252	522	25 249	1½	6.62	840.7	26 090
4	Heavy cast iron without caulking pockets.......	2 579	2 584	606	28 985	1¾	10.50	1 333.5	30 319

Weights of Various Types of Lining per Linear Foot of Tunnel.

Reference No.	Type of Lining.	Weights of complete rings (segments only), in pounds.	Weights of bolts, nuts, and washers, in pounds.	Weights of segments and bolts in tunnel complete, in pounds.
1	Ordinary cast iron without pockets........	9 273.0	336.3	9 609.6
2	Ordinary cast iron with pockets	9 158.8	336.3	9 495.2
3	Ordinary cast steel without pockets	10 099.6	336.3	10 436.0
4	Heavy cast iron without pockets..........	11 594.0	533.4	12 127.6

The weights in Table 18 are calculated by assuming cast iron to weigh 450 lb. per cu. ft., and cast steel 490 lb. In actual practice the "ordinary" iron was found to weigh a little more than the weights given, and the "heavy" a little less.

The silt in the sub-river portion averaged about 100 lb. per cu. ft., so that the weight of the silt displaced by the tunnel was about 41 548 lb. per lin. ft.

Taper Rings.—In order to pass around curves (whether horizontal or vertical), or to correct deviation from line or grade, taper rings were used; by this is meant rings which when in place in the tunnels were wider than the standard rings, either at one side (horizontal tapers or "Liners"), or at the top ("Depressors"), or at the bottom ("Elevators").

In the original design a ½-in. taper was called for, that is, the wide side of the ring was ½ in. wider than the narrow side, which was of the standard width of 2 ft. 6 in. As a matter of fact, during construction, not only ½-in., but ¾-in. and 1-in. tapers were often used.

These taper rings necessitated each plate having its own unalterable position in the ring, hence each plate of the taper ring was numbered, so that no mistake could be made during erection.

The taper rings were made by casting a ring with one circumferential flange much thicker than usual, and then machining off this flange to the taper. This was not only much cheaper than making a special pattern for each plate, but made it possible to see clearly where, and what, tapers were used in the tunnel.

Taper rings were provided for all kinds of lining (except the cast steel), and the lack of taper steel rings was felt when building the steel-lined parts of the tunnel, as nothing could be done to remedy deviations from line or grade until the steel section was over and cast iron could again be used. Table 19 gives the weights of the different kinds of tapers used.

TABLE 19.—WEIGHTS OF CAST-IRON TAPER RINGS, IN POUNDS PER COMPLETE RING.

Classification.	Weight of cast iron per complete ring, in pounds.
Ordinary pocketless ½-in. taper	23 767.7
" " 1- " "	24 352.4
" pocket ½- " "	23 481.7
Heavy pocketless ½-in. taper	29 564.8
" " ¾- " "	29 854.7
" " 1- " "	30 144.6

Cast-Steel Bore Segments and Accessories.—The following feature of these tunnels is different from any hitherto built. It was the original intention to carry the rolling load independent of the tunnel, or to assist the support of the silt portion of the structure by a single row of screw-piles, under each tunnel, and extending down to firmer ground than that through which the tunnels were driven. Therefore, provision had to be made whereby these piles could be put down through the invert of the tunnel with no exposure of the ground.

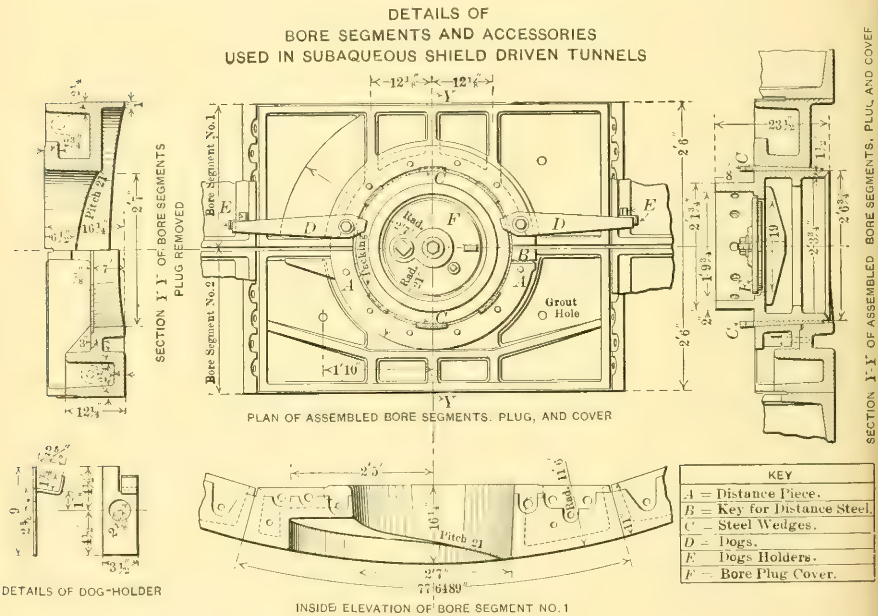


Fig. 12.

This provision was afforded by the "Bore Segments," which are shown in detail in Fig. 12. There are two segments, called No. 1 and No. 2, respectively. These two segments are bolted together in the bottom of two adjacent rings, and thus form a "Pile Bore." As the piles were to be kept at 15-ft. centers, and as the tunnel rings were 2 ft. 6 in. in length, it will be seen that, between each pair of bore-segment rings, there came four "Plain" rings. The plain rings were built up so that the radial joints broke joint from ring to ring, but with the bore-segment rings this could not be done, without unnecessarily adding to the types of segments.

The bore segments were made of cast steel, and were quite complicated castings, the principle, however, was quite simple. The segments provided an opening just a little larger than the shaft of the pile, the orifice being 2 ft. 7 in. in diameter at the smallest (lowest) point, while the shaft of the pile was to be 2 ft. 5¼ in. In order to allow of the entry of the screw-blade or helix of the pile, a slot was formed in the depth of Bore Segment No. 1, so that, when a pile was put in position above the bore, the blade, when revolved, would enter the slot and thus pass under the metal lining, although the actual orifice was only slightly larger than the pile shaft.

The wall of the pile orifice in Segment No. 2 was made lower than that in No. 1 so as to allow the blade to enter the slot in Segment No. 1. When the pile is not actually in process of being sunk, this lower height in No. 2 is made up with the removable "distance piece." This had a tongue at one end which engaged in a recess cast to take it in Segment No. 2 and was held in place by a key piece at the other end of the distance piece. Details of the distance piece and key are shown in Fig. 12.

The flanges around the pile bore were made flat and furnished with twelve tapped holes, six in Segment No. 1 and six in Segment No. 2, for the purpose of attaching the permanent arrangements in conjunction with which the pile was to be attached to the track system, independently of the tunnel shell, or directly to the tunnel. It was never decided which of these alternatives would be used, for, before this decision was reached, it was agreed that, at any rate for the present, it was better not to put down piles at all.

To close the bore, the "Bore Plug" was used. This is shown on Fig. 12. It was of cast steel, and was intended to act as a permanent point of the screw-pile, that is, the blade section was to be attached to the bore plug, the distance piece and key were to be removed, and the pile was to be rotated until the blade had cleared the slot; the distance piece and key were then to be replaced and sinking resumed.

The plug was held in place against the pressure of the silt by the two "dogs," while the dogs themselves were attached to the tunnel, as shown in Fig. 12. The ends of the dogs, which rested on the flanges of the metal lining of the tunnel, were prevented from being knocked off the flanges (and thus releasing the plug) by steel clips.

It was expected that it might be desirable to keep the lower end

of the piles open during their sinking, so that the bore plugs were not made permanently closed, but a seating was formed on the inner circumference of the plug, and on the seating was placed the "Plug Cover," made of cast iron, $18\frac{3}{4}$ in. in diameter and 3 in. thick, furnished with a lug for lifting and a 3-in. tapped hole closed by a screw-plug, through which any soundings or samples of ground could be taken prior to sinking the piles. This plug cover was held in place by a heavy steel "Yoke" under it, which engaged on the under side of the flange, on top of which the cover was set. The yoke was attached to the cover by a $1\frac{3}{4}$-in. tap-bolt, screwed into the yoke and passing through a 2-in. hole bored in the center of the cover. This rather peculiar mode of attaching the cover was adopted so that the cover could be removed by taking off the nut of the yoke, in case it was desired to open the end of the pile during the process of sinking.

The plug was a fairly close fit at the bottom of the orifice, that is, at the outside circumference of the tunnel, where the bore was 2 ft. 7 in. in diameter and the plug 2 ft. $6\frac{3}{4}$ in., but at the top of the bore-segment there was more clearance, as the plug was cylindrical while the bore tapered outward. To fill this space, it was intended that steel wedges should be used while the shield was being driven, so that they would withstand the crushing action of the thrusting shield, and, when the shield was far enough ahead, that they should be removed and replaced by hardwood wedges. This method was only used in the early weeks of the work; the modification of not using the shield-jacks which thrust against the bore segments was then introduced, and the wooden wedges were put in, when the bore plugs were set in place, and driven down to the stage of splitting.

When it was resolved not to sink the screw-piles, the bores had to be closed before putting in the concrete lining. This was done by means of the covers shown in Fig. 13. The bore plug and all its attachments were removed, and the flat steel cover, 2 in. thick and with stiffening webs on the under side, was placed over the circular flanges of the pile bore. The cover was attached to the bore segments by twelve $1\frac{1}{2}$-in. stud-bolts, 6 in. long, in the bolt holes already mentioned as provided on these flanges.

When these were in place, with lead grummets under the heads of the bolts and the grooves caulked, the bore segments were water-

tight, except in Bore Segment No. 2, at the joint of the distance piece; and, to keep water from entering here, this segment was filled to the level of the top of the flanges with 1 : 1 Portland cement mortar.

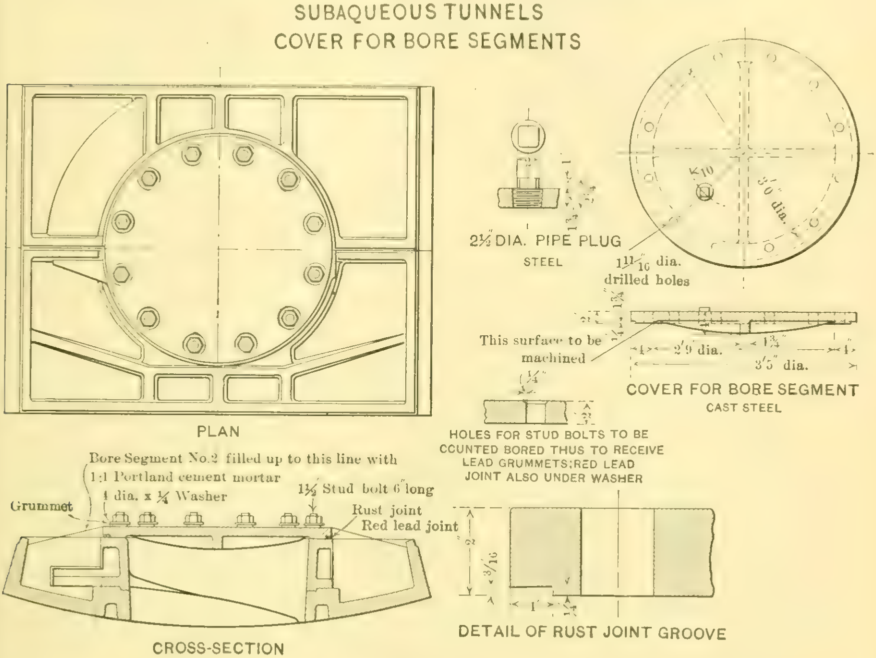


Fig. 13.

The weights of the various parts of the bore segments are given in Table 20.

TABLE 20.—Weights of Bore Segments and Accessories, in Pounds.

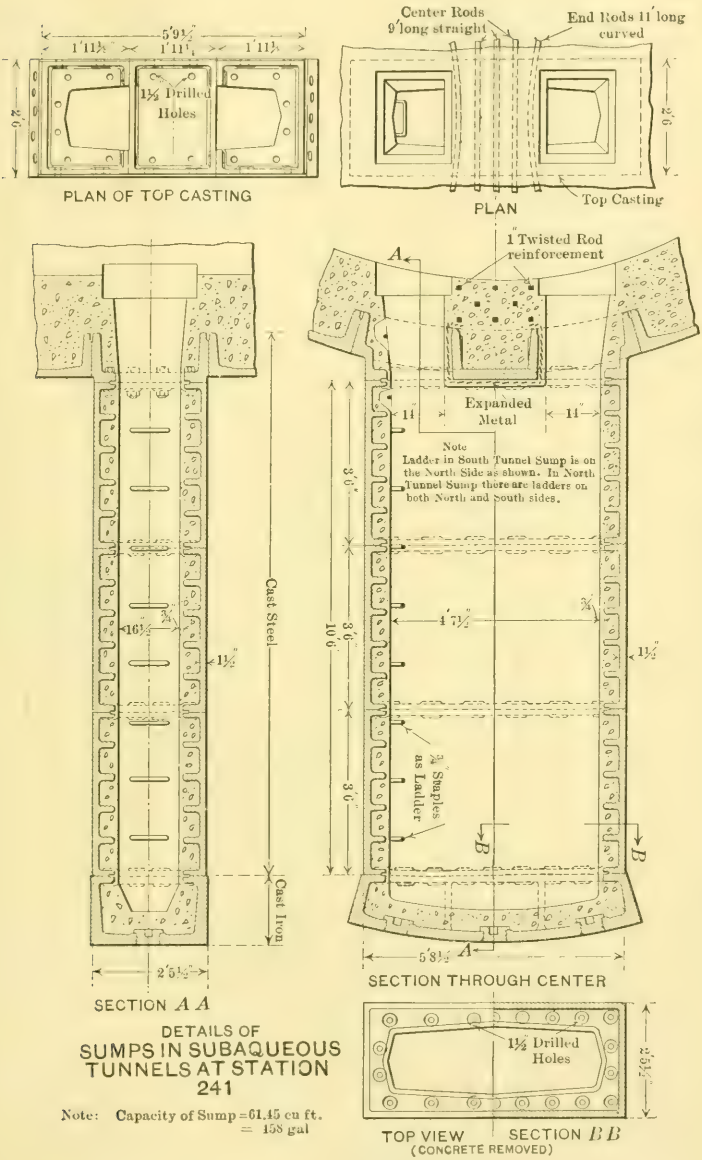
Part.	No.	Material.	Weight, in pounds.
Bore Segment No. 1	1	Cast steel	3 004.0
Bore Segment No. 2	1	" "	2 628.0
Distance piece	1	" "	423.5
Key	1	" "	34.3
Plug	1	" "	1 192.5
Yoke	1	" "	57.3
Dogs	2	" "	106.0
Slot cover	1	Rolled steel	6.4
Plug cover	1	Cast iron	162.0
Dog holders	2	Rolled steel	6.4
Complete weight of one pair, without bolts			7 620.4

Sump Segments.—In order to provide sumps to collect the drainage and leakage water in the subaqueous tunnels, special "sump segments" were installed in each tunnel at the lowest point—about Station 241 + 00. The details of the design are shown in Fig. 14. The segment was built into the tunnel invert as though it were an ordinary *"A"* segment. In building the sump, three lining castings were bolted, one on top of the other, and attached to the flat upper surface of the sump segment; meanwhile, the bolts attaching the sump segment to the adjacent tunnel plates were taken out and the plate and lining segments were forced through the soft mud by hydraulic jacks, the three 6-in. holes in the bottom of the sump segment being opened in order to minimize the resistance. The sump when built appeared as shown in Fig. 14, the top connection being made with a special casting, as shown.

The capacity of each sump is 500 gal., which is about the quantity of water entering the whole length of each subaqueous tunnel in 24 hours.

Cross-Passages.—When the contract was let, provision was made for cross-passages between the tubular tunnels, in the form of special castings to be built into the tunnel lining at intervals. However, the idea was given up, and these castings were not made. Later, however, after tunnel building had started, the question was raised again, and it was thought that such cross-connections would be very useful to the maintenance forces, that it might be possible to build them safely, and that their subsequent construction would be made much easier if some provision were made for them while the shields were being driven. It was therefore arranged to build, at intervals of about 300 ft., two consecutive rings in each tunnel, at the same station in each tunnel, with their longitudinal flanges together, instead of breaking joint, as was usually done. The keys of these rings were displaced twelve bolt holes from their normal positions toward the other tunnel. This brought the keys about 6 ft. above the bench, so that if they were removed, together with the *B* plates below them, an opening of about 5 by 7 ft. would be left in a convenient position with regard to the bench.

Nothing more was done until after the tunnels were driven. It was then decided to limit the cross-passages between the tubular tunnels to the landward side of the bulkhead walls. They were ar-



DETAILS OF
SUMPS IN SUBAQUEOUS TUNNELS AT STATION 241

Note: Capacity of Sump = 61.45 cu ft.
= 158 gal

FIG. 14.

ranged as follows: three on the New York side, at Stations 203 + 22, 206 + 80, and 209 + 80, and two on the New Jersey side, at Stations 255 + 46 and 260 + 14. The cross-passages are square in cross-section.

TABLE 21.—WEIGHTS OF SUMP SEGMENTS.

Part.	Number.	Material.	Weight, in pounds.
Middle top casting	1	Cast steel	880
End top castings	2	" "	1 718
Lining castings	3	" "	18 232
Sump segment	1	Cast iron	3 560
Total weight per sump, exclusive of bolts			24 390

Turnbuckle Reinforcement for Cast-Iron Segments.—During the period of construction, a certain number of cast-iron segments, mostly in the roof, but in some cases at Manhattan in the invert, behind the river lines, became cracked owing to uneven pressures of the ground. Before the concrete lining was put in, considerable discussion occurred as to the wisest course to pursue with regard to these broken plates. It was finally thought best not to take the plates out, as more harm than good might be done, but to reinforce them with turnbuckles, as shown in Fig. 15. The number of broken segments was distributed as follows:

North Manhattan Tunnel... 87, chiefly in silt (not under the river),
South Manhattan Tunnel... 7, chiefly in silt (" " " "),
North Weehawken Tunnel... 24, chiefly in sand (" " " "),
South Weehawken Tunnel.. 48, chiefly in silt, under the Fowler Warehouse.

The chief features of the tunnel lining have now been described, and, before giving any account of the methods of work, it will be well to mention briefly the salient features of the concrete lining which is placed within the actual lining.

Design of Concrete Lining.

This concrete lining will be considered and described in the following order:

The New York Shield Chambers,

Standard Cross-Section of Concrete Lining of Shield-Driven Tunnels,

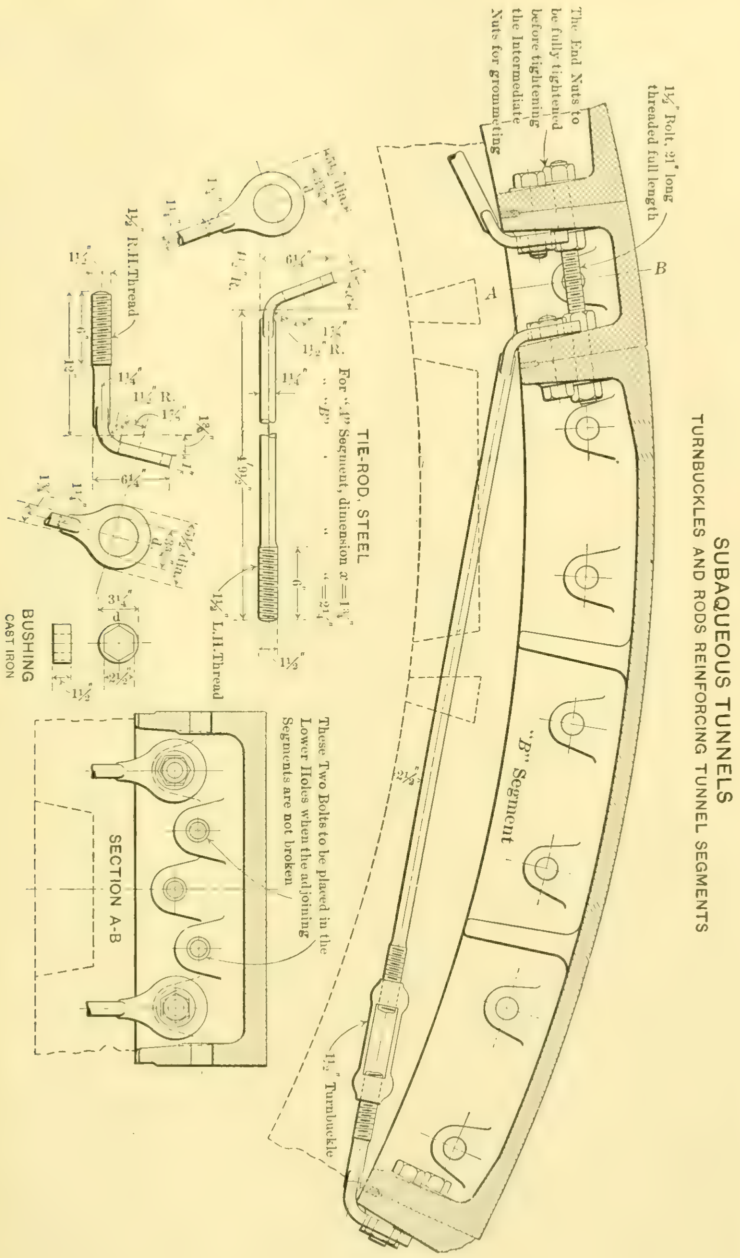
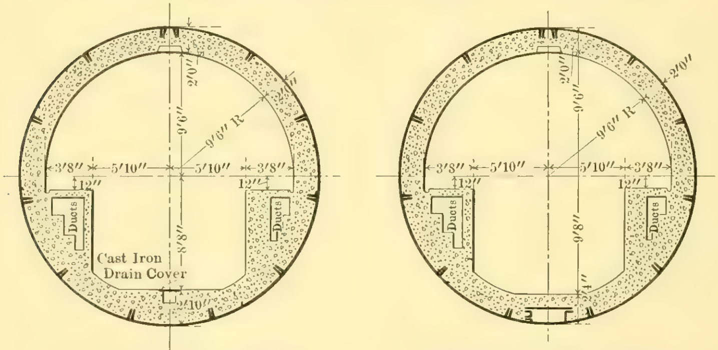

SUBAQUEOUS TUNNELS
TURNBUCKLES AND RODS REINFORCING TUNNEL SEGMENTS
1½" Bolt, 21" long threaded full length
The End Nuts to be fully tightened before tightening the Intermediate Nuts for grommeting
"B" Segment
1½" Turnbuckle
These Two Bolts to be placed in the Lower Holes when the adjoining Segments are not broken
SECTION A-B
TIE-ROD. STEEL
For "A" Segment, dimension x = 13"
1½" R.H.Thread
1½" L.H.Thread
BUSHING
CAST IRON

Fig. 15.

Final Lines and Grades, and How Obtained,
Steel Rod Reinforcement of Concrete,
Cross-Passage Lining, and
Special Provision for Surveys and Observations.

The New York Shield Chambers.—The cross-section of the concrete lining of these chambers is shown by Plate LXXXVI, referred to in the Land Tunnel Section. They are of the twin-tunnel double-bench type. The deep space beneath the floor is used as a sump for drainage, and manholes for access to the cable conduits are placed in the benches.

TYPES OF CONCRETE LINING OF SHIELD-DRIVEN TUNNELS.



IRON-LINED TUNNEL RESTING ON SOLID GROUND

IRON-LINED TUNNEL RESTING ON SOFT GROUND

Fig. 16.

Standard Cross-Section of Concrete Lining of Shield-Driven Tunnels.—The cross-section of the concrete lining of the tube tunnel is shown in Fig. 16. There are two main types, one extending from the shield chambers to the first bore segment, that is, to where the tunnel leaves solid ground and passes into silt, and the other which extends the rest of the way. The first type has a drain in the invert, the second has not.

The height from the top of the rail to the soffit of the arch being less than 16 ft. 11 in., overhead pockets for the suspension of electrical conductors were set in the concrete arch on the vertical axis line at 10-ft. centers. These pockets are shown in Fig. 16. The benches are utilized for the cable conduits in the usual way. Ladders are provided on one side at 25-ft. and on the other side at 50-ft.

intervals, to give access from the track level to the top of the benches. Refuge niches for trackmen are placed at 25-ft. intervals on the single-way conduits side only, as there is not enough room in front of the 4-way ducts. Manholes for giving access to the cable conduits, both power, and telephone and telegraph, are at 400-ft. intervals.

Final Lines and Grades, and How Obtained.—It may be well to explain here how the final lines and grades for the track, and therefore of the concrete lining, were obtained and determined. It is first to be premised that the standard cross-section of the tunnel (that is, of the concrete and iron lining combined) is not maintained throughout the tunnel. In other words, the metal lining is of course uniform, or practically so, throughout; the interior surface of the concrete lining is also uniform from end to end, but the metal lining, owing to the difficulty of keeping the shields, and hence the tunnels built within them, exactly on the true line and grade, is not on such lines and grades; the concrete lining is built exactly on the pre-arranged lines and grades, consequently, the relative positions of the concrete and metal linings vary continually along the length of the structure, according to whether the metal lining is higher or lower than it should be, further to the north or to the south, or any combination of these.

As before stated, it was strongly desired to encroach as little as possible on the standard 2-ft. concrete arch, and after some discussion it was decided that a thickness of 1 ft. 6 in. was the thinnest it was advisable to allow. This made it possible to permit the metal lining of the tunnel to be 6 in. lower, in respect to the level of the track at any point, than the standard section shows, and also allowed the center line of the track to have an eccentricity of 6 in. either north or south of the center line of the tunnel. This only left to be settled the extent to which the metal lining might be higher in respect to the track than that shown on the standard section.

This amount was governed by the desirability of keeping sufficient clearance between the top of the rail and the iron lining in the invert to admit of the attachment of pile foundations and all the accompanying girder-track system which would necessarily be caused by the use of piles, should it ever become apparent after operation was begun, that, after all, it was essential to have the tunnels supported in this way. Careful studies were made of the clearance necessary,

and it was decided that 4 ft. 9 in. was the minimum allowable depth from the top of the rail to the outside of the iron at the bottom. This meant that the iron lining could be 3 in. higher, with respect to the track level, than that shown on the standard section.

All the determining factors for fixing the best possible lines and grades for the track within the completed metal lining were now at hand. In March, 1908, careful surveys of plan and elevation were made of the tunnels at intervals of 25 ft. throughout. The following operations were then performed to fix on the best lines and grades:

First, for Line: It has been explained that the permissible deviation of the center line of the track on either side of the center line of the tunnel was 6 in. Had the metal lining been invariably of the true diameter, it would have been necessary to survey only one side of the tunnel; this would have given a line parallel to the center line, and might have been plotted as such; then, by setting off 6 in. on either side of this line, there would have been obtained a pair of parallel lines within which the center line of the track must lie. Owing to variations in the diameter of the tunnel, however, such a method was not permissible, and therefore the following process was used:

When running the survey lines through the tunnel (which were the center lines used in driving the shields), offsets were taken to the inner edges of the flanges of the metal lining, both on the north and south sides, at axis level at each 25-ft. interval. On the plat on which the survey lines were laid down, and at each point surveyed, a distance was laid off to north and south equal to the following distances:

Offset, as measured in the tunnel to north (or south), minus 10.08 ft.

This 10.08 ft. (or 10 ft. 1 in.) represents 10 ft. 7 in., the true radius to inside of iron, minus 6 in., the permissible lateral deviation of the track from the axis of the tunnel.

The result of this process was two lines, one on either side of the survey lines, not parallel to it or to each other, but approaching each other when the horizontal diameter was less than the true diameter, receding from each other when the diameter was more, and exactly 12 in. apart when the diameter was correct. As long as the center line of the track lay entirely within these two limiting lines, the con-

dition that the concrete arch should not be 6 in. less in thickness than the standard 2 ft. was satisfied, and in order to arrive at the final line, the longest possible tangents that would be within these limits were adopted as the final lines; and, as the survey lines were those used in driving the tunnel shields (that is, the lines to which it was intended that the track should be built), the amount by which the new lines thus obtained deviated from the survey lines was a measure of the deviation of the finally adopted track and concrete line from the original contract lines.

Next, for Grades: The considerations for grade were very similar to those for line. If the vertical diameter of the tunnel had been true at each 25-ft. interval surveyed, it would have been correct to plot the elevations of the crown (or invert) as a longitudinal section of the tunnel, and to have set up over those points others 6 in. above (as the metal lining could have been 6 in. lower than the standard section, which is equivalent to the track being an equal amount higher), and below these crown or invert elevations others 3 in. lower (as the metal lining could be 3 in. higher).

Then, by joining the points 6 in. above in one line and those 3 in. below in another, there would have been obtained lines of limitation between which the track grades must lie. However, as the tunnel diameter was not uniformly correct, a modification of this method had to be made, as in the case of the line determination, the principle, however, remaining the same.

The elevations were taken on the inner edges of the circumferential flanges of the metal lining, not only in the bottom, but also in the top, of the tunnel, at each 25-ft. interval; then, for the upper limit of the track at each such interval the following was plotted:

Elevation of inner edge of flange at top, minus 16.58 ft.

This 16.58 ft. (or 16 ft. 7 in.) was obtained thus: The standard height from the top of the rail to the inner edge of the iron flange is 17 ft. 1 in., but, as the track may be 6 in. above the standard or normal, the minimum height permissible is 16 ft. 7 in. For the lower limit of track at each 25-ft. interval the following was plotted:

Elevation of inner edge of flange at bottom, plus 3.83 ft.

This 3.83 ft. (or 3 ft. 10 in.) was obtained thus: The standard height from the top of the rail to the inner edge of the iron flange is 4 ft. 1 in. (5 ft. to outside of iron, less 11 in. for depth of flange),

but, as the track may be 3 in. below the standard, the minimum height permissible is 4 ft. 1 in. less 3 in., or 3 ft. 10 in.

By plotting the elevations thus obtained, two lines were obtained which were not parallel but were closer together or further apart according as the actual vertical diameter was less or greater than the standard, and the track grade had to lie within these two lines in order to comply with the requirements indicated above. The results of these operations for the North Tunnel are shown on Plate XC.

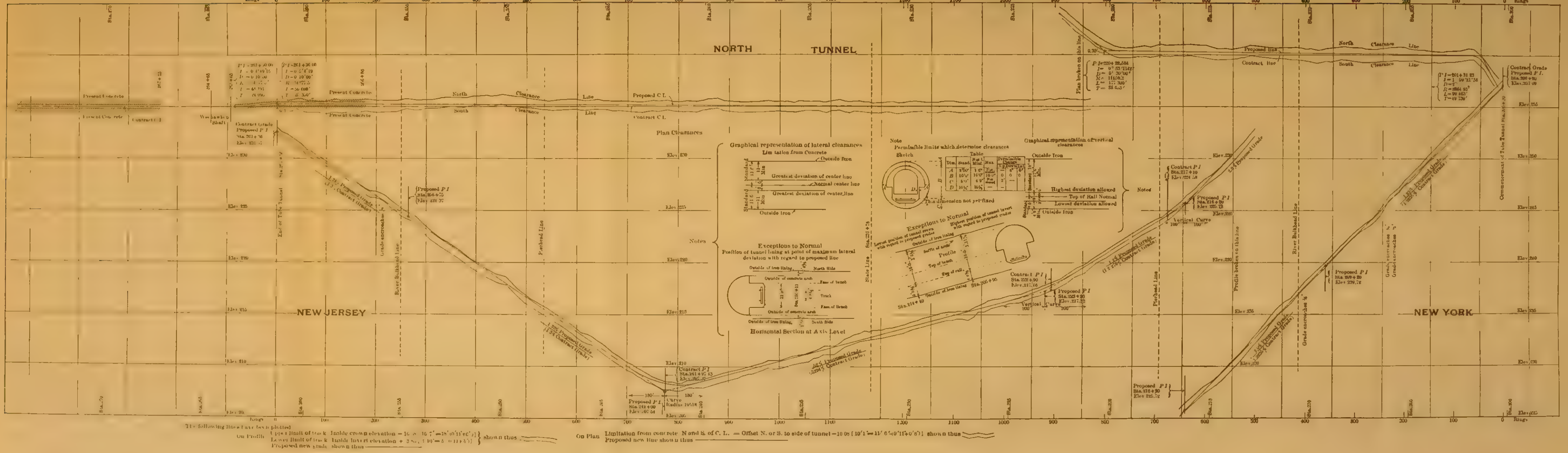
The greatest deviations between the lines and grades in the subaqueous tunnels as determined by these means and those as originally laid out in the contract drawings are on the Weehawken side, and were caused by the unexpected behavior of the tunnel when the shields were driven "blind" into the silt, causing a rise which could not be overcome, and the thrusting aside of one tunnel by the passage of the neighboring one. Had this unfortunate incident not occurred, it is clear that it would have been possible to adhere very closely indeed to the contract lines and grades, although the deviation is small, considering all things.

The internal outline of the concrete cross-section is uniform throughout, and is built on the lines and grades thus described.

Steel Rod Reinforcement of Concrete.—The original intention had been to line the metal lining of the tube tunnels with plain concrete, but, as the discussion on the foundation question continued, it was felt advisable, while still it was intended to put in the foundations, to guard against any stresses which were likely to come on the structure, by using a system of steel rods embedded circumferentially within the concrete. Designs were made on this basis, and even the necessary material prepared, before the decision to omit the piles altogether was reached. However, in order to provide a safeguard for the structure where it is partly or wholly beyond the solid rock, it was decided to use reinforcement, even with the piles omitted.

For this purpose the tunnel was considered as a girder, and longitudinal reinforcement was provided at the top and bottom. The top reinforcement extends from a point 25 ft. behind the point where the crown of the tunnel passes out of rock on the New York side to where the crown passes into rock on the New Jersey side. The bottom reinforcement extends from where the invert of the tunnel

DIAGRAM SHOWING NEW LINES AND GRADES IN RIVER TUNNEL NORTH, MAY 13, 1908



passes out of rock on the New York side to where it passes into rock on the New Jersey side.

The reinforcement both at top and bottom consists of twenty 1-in. square twisted rods, ten placed symmetrically on either side of the vertical axis, 9 in. apart from center to center and set 4 in. (to their centers) back from the face of the concrete.

As a further precaution, circumferentially-placed rods were used on the landward side of the river lines, mainly to assist in preventing the distortion of shape which might occur here, either under present conditions, such as under the Fowler Warehouse at Weehawken, or under any possible different future conditions, such as might be brought about by building some new structure in the vicinity of the tunnels.

For purposes of classification of the circumferential reinforcement, the tunnel was divided into two types, *"B"* and *"C"*; (Type *"A"* covering the portion which, being wholly in solid rock, was not reinforced at all).

Type *"B"* covers the part of the tunnels on both sides of the river lying between the point where the top of the tunnel passes out of rock and the point where the invert passes out of rock on the Manhattan side, or out of gravel on the Weehawken side. The reinforcement consists of twenty 1-in. square longitudinal rods in the crown of the tunnel, as described for the general longitudinal reinforcement, together with 1-in. square circumferential rods at 10-in. centers, and extending over the arch to 2 ft. 3 in. below the horizontal axis.

Type *"C"* extends from the latter limit of Type *"B"* to the river line on each side, and consists of longitudinal reinforcement in both top and bottom, as described before, together with circumferential reinforcement entirely around the tunnel, and formed of 1-in. square twisted rods at 15-in. centers.

Type *"D"* consists of longitudinal reinforcement only, and extends from river line to river line, thus occupying 72.5% of the length in which concrete is used. The reinforcement consists of twenty 1-in. twisted rods at 9-in. centers in the crown, and twenty 1-in. rods at 9-in. centers in the invert. In addition to the three standard types, *"B," "C,"* and *"D,"* there were two sub-types which were used in Type *"D,"* and in conjunction with it wherever the thickness of the center of the concrete arch became less than 1 ft. 6 in., measuring to

the outside of the metal lining. This thickness was one of the limits used in laying out the lines and grades, and in general the arch was not less than this. There were one or two short lengths, however, where it was less, for, if the arch thickness requirement had been adhered to, it would have resulted in a break of line or grade for the sake of perhaps only a few feet of thin arch, and it was here that the sub-types came into play.

Sub-type 1 was used where the arch was less than 1 ft. 6 in. thick at the top. The extra reinforcement here consisted of 1-in. square twisted rods, 16 ft. long, laid circumferentially in the crown at 10-in. centers.

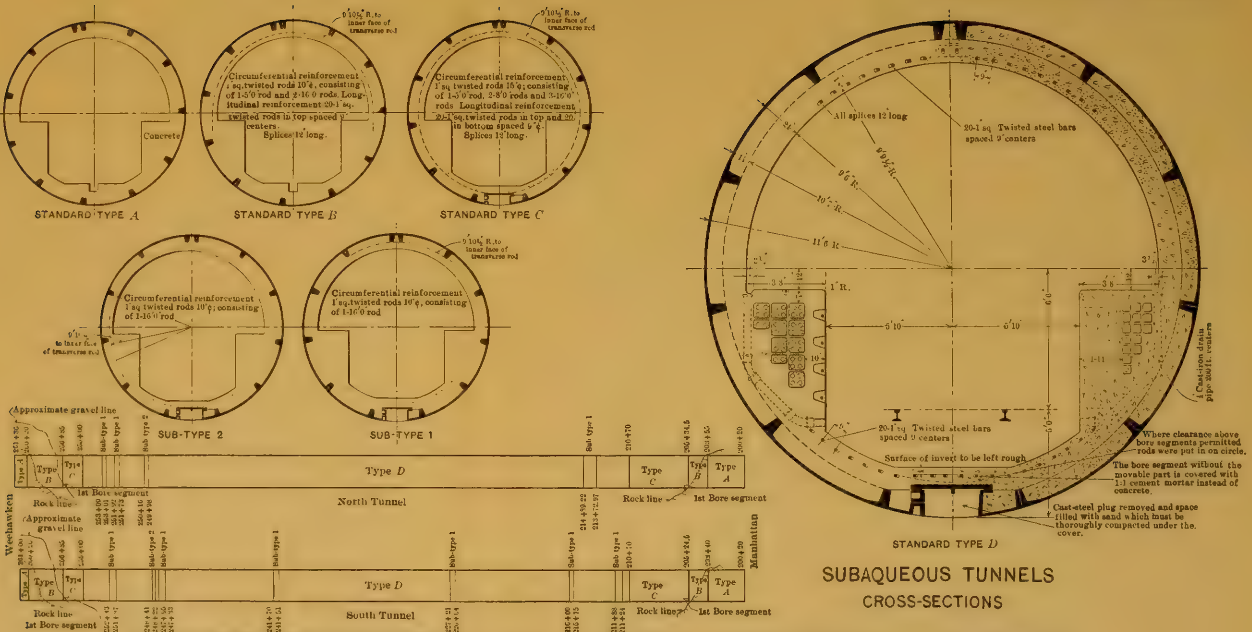
Sub-type 2 was used where the arch was less than 1 ft. 6 in. thick at the side. The extra reinforcement here consisted of 1-in. square twisted rods, 16 ft. long, laid circumferentially, at the side on which the concrete was thin, at 10-in. centers. Very little of either of these two sub-types was used. The entire scheme is shown graphically and clearly on Plate XCI.

Cross-Passage Lining.—There are two main types of cross-passages: Lined with steel plates, and unlined.

There is only one example of lining with steel plates, namely, the most western one at Weehawken. This is built in rock which carried so much water that, in order to keep the tunnels and the passage dry, it was decided to build a concrete-lined passage, without attempting to stop the flow of water, and within this to place a riveted steel lining, not in contact with the concrete, but with a space between the two. This space was drained and the water led back to the shield chamber and thence to the Weehawken Shaft sump. The interior of the steel lining is covered with concrete.

In the passages not lined with steel plates the square concrete lining is rendered on the inside with a water-proof plaster. Each of the passages is provided with a steel door.

Provisions in Concrete Lining for Surveys and Observations.—The long protracted discussion as to the provision for foundations in these tunnels led to many surveys, tests, and observations, which were carried out during the constructive period, and, as it was desired to continue as many of these observations as possible up to and after the time when traffic started, certain provisions were made in the



SUBAQUEOUS TUNNELS
CROSS-SECTIONS

SUB-TYPES OF REINFORCEMENT, COMBINED WITH STANDARD

Sub Type	Description of Location	Description of Lining	Total linear feet of tunnels	Wt. of steel per lin. ft. of tunnel	Total wt. of steel
1	Where concrete lining is less than 18" thick in the crown	1" square twisted circumferential rods in crown 10 centers, 16'0 long.	435.25	66 048	28.746
2	Where concrete lining is less than 18" thick at side.	1 square twisted circumferential rods at side 10 centers, 16'0 long.	37	66.048	2.444

Note:
Above estimates of weights are based on a weight of 3.44 lb. per linear ft. of bar and an assumed average net length of longitudinal bar of 11'0."

STANDARD CONCRETE LINING

Type	Description of Location	Description of Lining	Total linear feet of tunnels	Wt. of steel per lin. ft. of tunnel	Total wt. of steel
A	In full rock.	Plain concrete	851		
B	From about 20 ft. within fullrock to where rock disappears in bottom of tunnel in Manhattan and where gravel and sand disappear in bottom of tunnel in Weehawken.	20-1" sq. twisted longitudinal rods in top 9'6 1" sq twisted circumferential rods in arch 10" centers	1034	228.42	236 181
C	From where rock disappears in Manhattan and gravel and sand in Weehawken to river lines.	20-1" sq. twisted longitudinal rods in top and 20 in bottom 9'6.1 sq twisted circumferential rods all around 15" centers.	1451	341.25	495 153
D	Between river lines.	20-1" sq. twisted longitudinal rods in top and 20" in bottom, 2" centers.	8860	151.36	1 341 050

concrete lining whereby these requirements might be fulfilled. The chief points on which information was desired were as follows:

The change in elevation of the tunnel,
The change in lateral position of the tunnel,
The change in shape of the tunnel,
The tidal oscillation of the tunnel.

A detailed account of these observations will be found in another paper on this work, but it may be said now that it was very desirable to be able to get this information independently of the traffic as far as possible, and therefore provision was made for carrying on the observations from the side benches.

For studying the changes in level of the tunnel, a permanent bench-mark is established in each tunnel where it is in the solid rock and therefore not subject to changes of elevation; throughout the tunnel, brass studs are set in the bench at intervals of about 300 ft. A series of levels is run every month from the stable bench-mark on each of these brass plugs, thus obtaining an indication of the change of elevation that the tunnels have undergone during the month.

These results are checked on permanent bench-marks in the subaqueous portion of the tunnels. These consist of rods, encased in pipes of larger diameter, which extend down through the tunnel invert into the bed-rock below the tunnel. Leakage is kept out by a stuffing-box in the invert. By measuring between a point on these rods where they pass through the invert and the tunnel itself a direct reading of the change of elevation of the tunnel is obtained. These measurements are taken at weekly intervals, and, as the tunnels are subject to tidal influences, being lower at high tide than at low tide, are always taken under the same conditions as to height of water in the river. These permanent bench-marks are at Stations 209 + 05 and 256 + 02 (about 100 ft. on the shoreward side of the river line in each case) in the South Tunnel, at Stations 220 + 00 and 243 + 86, also in the South Tunnel, and at Station 231 + 78 in the North Tunnel. In order to study the lateral change of position, a base line was established on the side bench at each end of each tunnel in the portion built through the solid rock.

At intervals of about 300 ft. throughout each tunnel, alignment pockets are formed in the concrete arch, also above the bench, on the

south bench of the North Tunnel and the north bench of the South Tunnel. In each pocket is placed a graduated and verniered brass bar, so that, when the base line is projected on these bars, the lateral movement of the tunnel can be read directly. As it was desirable to have as much cross-connection as possible between the tunnels at the points where the instruments were to be set up, five of the main survey stations were set opposite each of the five cross-passages. Then, for the purpose of increasing the cross-connection still further, pipes 6 in. in diameter were put through from one tunnel to the other at axis level at Stations 220 + 60, 231 + 78, 234 + 64, 241 + 99, and 251 + 13, and a survey station was put in opposite each one

Points were established at Station 220 + 00, which is the point of intersection for the curve on the original center line of the tunnel, and also at Station 220 + 23, where the intersection of the track center line comes in the North Tunnel. As it was desirable to have the survey stations not much more than 300 ft. apart, so as to obtain clear sights, other stations were established so that the distances between survey stations were at about that interval.

For studying changes of shape in the tunnel, brass "diameter markers" were inserted at each survey station in the concrete lining at the extremities of the vertical and horizontal axes. These were pieces of brass bar, $\frac{3}{8}$ in. in diameter and 6 in. long, set in the concrete and projecting $\frac{5}{8}$ in. into the tunnel, so that a tape could be easily held against the marker and read.

For obtaining the tidal oscillation of elevation of the tunnel, recording gauges are attached to the invert of the tunnel at each of the five permanent bench-marks referred to above in such a way that the recording pencil of the gauge is actuated by the rod of the permanent bench-mark. A roll of graduated paper is driven by clockwork below the recording pencil which thus marks automatically the relative movement between the moving tunnel and the stable rods. These have shown that in the subaqueous part of the tunnel there is a regular tidal fluctuation of elevation, the tunnel moving down as the tide rises, and rising again when the tide falls. For an average tide of about 5 ft. the tunnel oscillation would be about $\frac{1}{8}$ in. Before the concrete lining was placed, there was a tidal change in the shape of the tunnel, which flattened about $\frac{1}{64}$ in. at high tide. After the concrete lining was placed, this distortion seemed to cease.

The general design and plan of the work have been described, and before giving any account of the contractor's methods in carrying it out, Table 22, showing the chief quantities of work in the river tunnels, is presented.

Actual Methods of Construction.

The following is an account of the methods used by the contractor in carrying out the plans which have already been described. First, it may be well to point out the sequence of events as they developed in this work. These events may be divided into six periods.

1.—Excavation and Iron Lining: June, 1903, to November, 1906;

2.—Caulking and grummeting the iron lining: November, 1906, to June, 1907;

3.—Surveys, tests and observations: April, 1907, to April, 1908;

4.—Building cross-passages and capping pile bores: April, 1908, to November, 1908;

5.—Placing the concrete lining: November, 1908, to June, 1909;

6.—Cleaning up and various small works: June, 1909, to November, 1909.

The tunnels were under an average air pressure of 25 lb. per sq. in. above normal for all except Periods 5 and 6, during which times there was no air pressure in the tunnels.

All the work will be described in this paper except that under Period 3 which will be found in another paper.

Period 1.—Excavation and Iron Lining, June, 1903, to November, 1906.—Table 23 gives the chief dates in connection with this period.

Manhattan Shield Chambers.—The Manhattan shield chamber construction will be first described. The Weehawken shield chambers have been described under the Land Tunnel Section, as they are of the regular masonry-lined Land Tunnels type, whereas the Manhattan chambers are of segmental iron lining with a concrete inner lining.

During the progress of excavation, the location of the New York shield chambers was moved back 133 ft., as previously described in the "Land Tunnel" Section, and when the location had been finally decided, there was a middle top heading driven all through the length now occupied by the shield chamber. Narrow cross-drifts were taken out at right angles to the top heading, and from the ends of these the wall-plate headings were taken out. Heavy timbering was used, as

TABLE 22.—QUANTITIES OF WORK IN SUBAQUEOUS TUNNELS.

Description, Quantity Length, Etc.		Type.					
		Manhattan shield chambers.	Cast iron, ordinary pocketless.	Cast iron, ordinary pocket.	Cast iron, heavy pocketless.	Cast steel, ordinary pocketless.	Total.
Length, in feet.		59.00	4 374.99	2 146.3	5 522.05	152.66	12 255.00 ft.
Excavation, in cubic yards.	Total	1 884	67 344	33 038	85 001	2 349	189 616 cu. yd.
	Per linear foot	31.9	15.4	15.4	15.4	15.4	....
Cast-iron tunnel lining, in pounds.	Total	847 042	39 643 120	19 715 405	61 559 845	....	121 765 412 lb.
	Per linear foot	14 357	9 061	9 186	11 148	....	....
Cast-steel tunnel lining, in pounds.	Total	....	1 544 962	757 938	2 730 905	1 549 711	6 583 516 lb.
	Per linear foot	....	353.1	353.1	494.5	10 151.4	....
Steel bolts and washers, in pounds.	Total	23 627	1 475 991	724 095	2 935 455	51 266	5 210 434 lb.
	Per linear foot	400.46	337.37	337.00	531.59	335.82	....
Rust joints, in linear feet.	Total	3 376	170 755	83 935	218 656	5 996	482 718 ft.
	Per linear foot	57.2	39.0	39.1	39.6	39.3	....
Concrete, in cubic yards.	Total	766	20 030	9 827	25 282	713	56 618 cu. yd.
	Per linear foot	12.98	4.58	4.58	4.58	4.58	....
Steel beams, plates, etc., in pounds.	Total	12 346	83 774	41 098	105 738	7 432	250 388 lb.
	Per linear foot	2 092.5	19.1	19.1	19.1	48.7	....
Steel bolts, hooks, etc., in pounds.	Total	1 328	36 980	18 142	46 675	1 471	104 596 lb.
	Per linear foot	22.5	84.5	84.5	84.5	96.4	....
Expanded metal, in pounds.	Total	594	2 215	1 086	2 795	62	6 752 lb.
	Per linear foot	10.07	0.506	0.506	0.506	0.406	....
Vitrified conduits, in duct feet.	Total	2 560	235 903	115 728	297 752	7 757	659 700 duct ft.
	Per linear foot	43.49	53.92	53.92	53.92	50.81	....

TABLE 23.—EXCAVATION AND IRON LINING.

	North Manhattan.	North Weehawken.	South Manhattan.	South Weehawken.
Shaft and preliminary headings.......Begun...	June 10, '03.	June 11, '03.	June 10, '03.	June 11, '03.
Shaft and preliminary headings.......Finished.	December 11, '03.	September 1, '04.	December 11, '03.	September 1, '04.
Excavation of shield chamber.......Begun...	May 24, '04.	January 16, '05.	May 24, '04.	January 16, '05.
Excavation of shield chamber.......Finished.	January 21, '05.	March 25, '05.	May 13, '05.	April 19, '05.
Cast-iron lining of shield chambers.......Begun...	February 4, '05.	None.	May 15, '05.	None.
Cast-iron lining of shield chambers.......Finished.	March 13, '05.	None.	June 14, '05.	None.
Excavation of tunnels begun before installation of shield.......	October 17, '04.	January 13, '05.	January 5, '05.	January 25, '05.
Commenced building falsework for shield.......	March 6, '05.	March 23, '05.	June 19, '05.	April 17, '05.
Shield parts received at shaft.......	March 11, '05.	March 20, '05.	June 22, '05.	April 24, '05.
Erection of shield begun.......	March 13, '05.	March 27, '05.	June 22, '05.	April 24, '05.
Erection of shield (structural steel).......Finished.	March 27, '05.	April 12, '05.	June 8, '05.	May 6, '05.
Erection of shield (hydraulic fittings).......Finished.	May 11, '05.	May 25, '05	August 27, '05.	June 13, '05.
First ring of permanent cast-iron lining put in.......	May 12, '05.	May 29, '05.	August 27, '05.	June 14, '05.
First air lock bulkhead wall.......Begun...	May 29, '05.	June 15, '05.	September 18, '05.	June 21, '05.
First air lock bulkhead wall.......Finished.	June 7, '05.	June 23, '05.	September 23, '05.	July 3, '05.
Air pressure first put in tunnel.......	June 25, '05.	June 29, '05.	October 6, '05.	July 8, '05.
Rock disappeared from invert of tunnel.......	December 1, '05.	October 31, '05.	February 8, '06.	September 21, '05.
First pair of bore segments built in tunnel.......	December 9, '05.	January 12, '06.	February 16, '06.	December 12, '05.
Rip-rap of river bulkhead wall met.......	February 8, '06.	None.	April 11, '06.	None.
First pile met (in river bulkhead wall at Manhattan, and Fowler warehouse foundation at Weekawken).......	February 18, '06.	January 3, '06.	April 18, '06.	December 4, '06.
Last pile met.......	March 2, '06.	February 5, '06.	May 1, '06.	January 9 '06.
First ring erected on river side of shore line.......	March 3, '06.	February 6, '06.	May 9, '06.	January 19, '06.
Removing hood of shield.......Begun...	March 27, '06.	February 6, '06.	May 9, '06.	January 19, '06.
Removing hood of shield.......Finished.	April 1, '06.	February 8, '06.	May 12, '06.	January 24, '06.
Second air-lock bulkhead wall.......Begun...	May 12, '06.	March 19, '06.	July 13, '06.	March 11, '06.
Second air-lock bulkhead wall.......Finished.	May 21, '06.	March 24, '06.	July 21, '06.	March 18, '06.
Tunnel holed through with meeting tunnel.......	September 12, 1906.		October 9, 1906.	
Last ring of permanent cast-iron lining built in.......	October 9, 1906.		November 18, 1906.	

the rock cover was only about 6 ft., and the whole span to be covered was 60 ft. The process adopted was to excavate and timber the north side first, place the iron lining, and then excavate the south side, using the iron of the north side as the supports for the north ends of the segmental timbering of the south. The only incident of note was that at 2:00 A. M., on October 20th, 1904, the rock at the west end of the south wall-plate heading was pierced. Water soon flooded the workings, and considerable disturbance was caused in the New York Central Railroad yard above. The cavity on the surface was soon filled in, but to stop the flow of mud and water was quite a troublesome job.

The excavation was begun on May 24th, 1904, and finished on May 15th, 1905. The segments were placed by an erector consisting of a timber boom supported by cross-timbers running on car wheels on longitudinal timbers at each side of the tunnel. Motion was transmitted to the boom by two sets of tackle, and the heavy (5 000-lb.) segments were easily handled. The erection of the lining was started on February 4th, 1905, and finished on June 14th, 1905.

While the shield chambers were being excavated, bottom headings were run along the lines of the river tunnels and continued until the lack of rock cover prevented their being driven further. These were afterward enlarged to the full section as far as possible. The typical working force in the shield chambers was as follows:

Ten-hour Shifts.

Drilling and Blasting.

1 Foreman	@	$3.50
6 Drillers	"	3.00
6 Drillers' helpers	"	2.00
1 Blacksmith	"	3.50
1 Blacksmith's helper	"	2.25
1 Powderman	"	2.00
1 Waterboy	"	2.00
1 Nipper	"	2.00
1 Machinist	"	3.00
1 Machinist's helper	"	1.80

Mucking.

1 or 2 Foremen	@	$3.00
16 Muckers	"	2.00

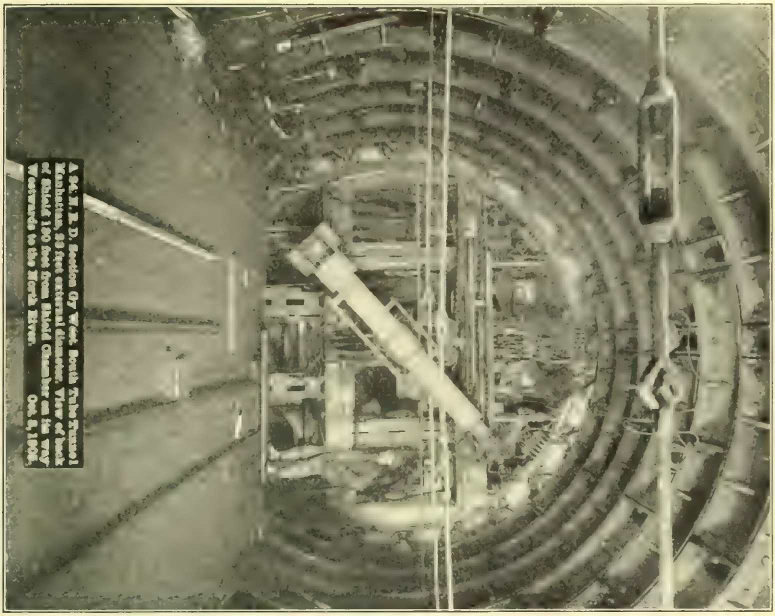

A 24 N. R. D. Section Gy West. South Tube Tunnel Manhattan, 23 feet external diameter. View of back of Shield 130 feet from Shield Chamber on its way Westwards to the North River. Oct. 3, 1906.

Fig. 1.

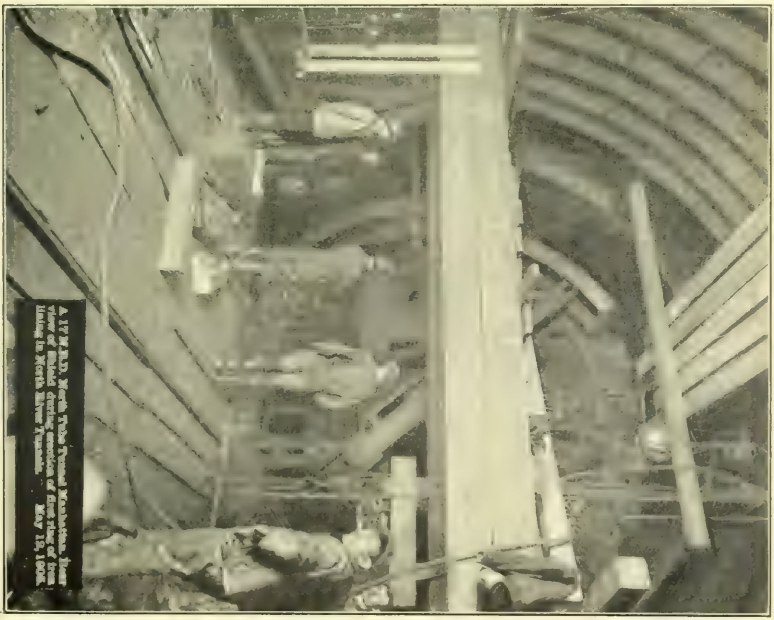

A 17 N.R.D. North Tube Tunnel Manhattan. Rear view of Shield during erection of first ring of iron lining in North River Tunnels. May 12, 1906.

Fig. 2.

Erection of Shields.—The tunneling shields have been described in some detail in the section of this paper dealing with the contractor's plant. They consist essentially of two parts, the structural steelwork and the hydraulic fittings. The former was made by the Riter Conley Manufacturing Company, of Pittsburg, Pa., and put up by the Terry and Tench Company, of New York City; the hydraulic fittings were made and put in by the Watson-Stillman Company, of New York City.

On the New York side, the shields were built inside the iron lining of the shield chambers, hence no falsework was needed, as the necessary hoisting tackle could be slung from the iron lining; at Weehawken, however, the erection was done in the bare rock excavation, so that timber falsework had to be used. The assembly and riveting took about 2 weeks for each shield; the riveting was done with pneumatic riveters, using compressed air direct from the tunnel supply.

After the structural steel had been finished, the shields, which had hitherto been set on the floor of the chambers in order to give room for working over the top, were jacked up to grade; this involved lifting a weight of 113 tons. While the hydraulic fittings were being put in, the shields were moved forward on a cradle, built of concrete with steel rails embedded, on which the shield was driven for the length in which the tunnel was in solid rock.

The installation of the hydraulic fittings took from 4 to 6 weeks per shield. The total weight of each finished shield was about 193 tons. The completed shield, as it appeared in the tunnel, is shown by Fig. 1, Plate XCII. The typical force working on shield erection was as follows:

Ten-hour Shifts.

Shield Erection. (*Terry and Tench.*)

1	Superintendent..................	@	$13.00	per day
4	Foremen..........................	"	5.50	" "
1	Timekeeper.......................	"	2.50	" "
2	Engineers........................	"	4.50	" "
34	Iron workers.....................	"	4.50	" "
7	Laborers.........................	"	2.25	" "

Hydraulic Work. (*Watson-Stillman Company.*)

4	Mechanics........................	@	$4.00	per day

General Labor. (*O'Rourke Engineering Construction Company.*)

1 Inspector........................	@ $4.00 per day
1 Foreman........................	" 4.00 " "
8 Laborers........................	" 2.00 " "
1 Engineer........................	" 2.50 " "

After the shield was finished and in position, the first two rings of the lining were erected in the tail of the shield. These first rings were then firmly braced to the rock and the chamber lining; then the shield was shoved ahead by its own jacks, another ring was built, and so on.

The description of the actual methods of work in the shield-driven tunnels can now be given; this will be divided generally into the different kinds of conditions met at the working face, for example, Full Face of Rock, Mixed Face, Full Face of Sand and Gravel, Under River Bulkhead, and Full Face of Silt.

The last heading is the one under which by far the longest length of tunnel was driven, and, as not much has hitherto appeared descriptive of the handling of a shield through this material, considerable space will be devoted to it.

Full Face of Rock.—As was described when dealing with the shield chambers, as much as possible of the rock excavation was done before the shields were installed. On the New York side, about 146 ft. of tunnel was completely excavated, with 71 ft. of bottom headings beyond that, and at Weehawken, 58 and 40 ft. of tunnel and heading beyond, respectively. This was chiefly done to avoid handling the rock through the narrow shield doors. Test holes were driven ahead at short intervals to make sure that the rock cover was not being lost, but, nevertheless, at Weehawken, on February 14th, 1905, a blast broke through the rock and let the mud flow in, filling the tunnel for half its height for a distance of 300 ft. from its face.

Throughout the rock section the shield traveled on a cradle of concrete in which were embedded either two or three steel rails. In the portion in which the whole of the excavation had been taken out, it was only necessary to trim off projecting corners of rock. In the portion in which only a bottom heading had been driven, the excavation was completed just in front of the shield, the drilling below axis level being done from the heading itself, and above that

from the front sliding platforms of the shield. The holes were placed near together and drilled short, and very light charges of powder were used, so as to lessen the chance of knocking the shield about too much. In this work the small shield doors hampered the work greatly, and it might have been well to have provided a larger bottom opening which could have been subdivided or partly closed when soft ground was met; on the other hand, the quantity thus handled was small, owing to the fact that the greater part of the rock was excavated before the shields were installed.

The space outside the lining was grouted with a 1:1 mixture of Portland cement and sand. Large voids were hand-packed with stone before grouting. The details of grouting will be described later.

A typical working gang is given herewith. Two such gangs were worked per shield per 24 hours, 10 hours per shift. All this work was done under normal air pressure.

General:			
½ Tunnel superintendent	@	$200.00	per month
1 Assistant tunnel superintendent	"	5.00	per day
1 General foreman	"	5.00	" "
½ Electrician	"	3.50	" "
½ Electrician's helper	"	3.00	" "
½ Pipefitter	"	3.00	" "
½ Pipefitter's helper	"	2.75	" "
Drilling:			
1 Foreman	"	5.00	" "
3 Drillers	"	4.00	" "
3 Drillers' helpers	"	3.00	" "
1 Nipper	"	2.50	" "
½ Waterboy	"	2.50	" "
½ Powderboy	"	2.75	" "
Mucking:			
1 Foreman	"	3.50	" "
8 Muckers	"	2.75	" "
Erecting Iron and Driving Shield:			
1 Erector runner	"	4.00	" "
3 Iron workers	"	3.00	" "

The duties of such a gang were as follows: The tunnel superintendent looked after both shifts of one shield. The assistant or "walking boss" had charge of all work in the tunnel on one shift. The general foreman had charge of the labor at the face. The electricians looked after repairs, extensions of the cables, and lamp renewals. The pipefitters worked in both tunnels repairing leaks in pipes between the power-house and the working faces, extending the pipe lines, and attending to shield repairs, and in the latter work the erector runner helped.

The drillers stuck to their own jobs, which were not subject to interruption as long as the bottom headings lasted. One waterboy and one powderboy served two tunnels. The muckers helped the iron men put up the rings of lining, as well as doing their own work. The iron men tightened bolts, whenever not actually building up iron. The list does not include the transportation gang, which will be described under its own heading.

The rate of progress attained was 4.2 ft. per day per shield where most of the excavation had been done before, and 2.1 ft. where none had been done before.

When the shields had got far enough away from the shield chamber, and before rock cover was lost, the first air-lock bulkhead walls were put in.

Air-Lock Bulkhead Walls.—The specifications required these walls and all their fittings to be strong enough to stand a pressure of 50 lb. per sq. in. Accordingly, all the walls were of concrete, 10 ft. in thickness, except the first two, which were 8 ft. in thickness, and grouted up tight.

There were three locks in each bulkhead wall capable of holding men, namely, the top or emergency lock which is set high in order to afford a safe means of getting away in case of a flood; this lock was used continuously for producing the lines and levels into the tunnels. It was very small and cramped for this purpose, and a larger one would have been better, both for lines and emergencies. This lock was directly connected with the overhead platform (also called for in the specifications) which ran the whole length of the tunnels. Side by side, on the level of the lower or working platform of the tunnel, were the man lock and the muck lock. In addition a number of pipes were built in to give access to the cables and for passing pipes, rails, etc., in and out.

After each tunnel was about 1 200 ft. ahead of the first walls, a second wall was built just like the first, and no others were put in, so that altogether there were eight walls. This second wall not only gave an added safeguard to the tunnel but enabled the air pressure at the working face to be divided between the two walls, and this compression or decompression in stages, separated by a spell of walking exercise, was found to be very good for the health of those working in the air.

Mixed Face.—When the rock cover became so thin that it was risky to go on without the air pressure, the air pressure was turned on, starting with from 12 to 18 lb., which was enough to stop the water from the gravel on top of the rock. At first, when the surface of the rock was penetrated, the soft face was held up by horizontal boards braced from the shield until the shield was shoved. The braces were then taken out and, as soon as the shield had been shoved, were replaced by others. As the amount of soft ground in the face increased, the system of timbering was gradually changed to one of 2-in. poling boards resting on top of the shield and supported at the face by vertical breast boards, in turn held by 6 by 6-in. walings braced both through the upper doors to the iron lining and from the sliding platforms of the shield. The latter were in their forward position before the shield was shoved, the pressure being turned off and the exhaust valves opened just before the shove began. As the shield went ahead, the platform jacks gradually exhausted and thus held enough pressure on the face to keep it up. Fig. 17 is a sketch of this method. In driving through mixed ground a typical working gang was about as follows:

General:			
$\frac{1}{3}$ Tunnel superintendent..........	@	$300.00	per month
1 Assistant tunnel superintendent	"	5.00	per day
1 General foreman..............	"	5.00	" "
$\frac{1}{2}$ Electrician....................	"	3.50	" "
$\frac{1}{2}$ Electrician's helper............	"	3.00	" "
$\frac{1}{2}$ Pipefitter......................	"	3.25	" "
$\frac{1}{2}$ Pipefitter's helper..............	"	3.00	" "
Drilling:			
1 Foreman......................	"	5.00	" "
2 Drillers......................	"	3.25	" "
2 Drillers' helpers................	"	3.00	" "

Timbering:				
2 Timbermen	@	$2.50	per	day
2 Timbermen's helpers..........	"	2.00	"	"
Mucking:				
1 Foreman......................	"	3.50	"	"
6 Muckers......................	"	2.75	"	"
Erecting Iron and Driving Shield:				
1 Erector runner................	"	3.25	"	"
3 Iron workers..................	"	3.00	"	"

The average rate of progress was 2.6 ft. per day.

In this case there were three such gangs, each on an 8-hour shift.

Full Face of Sand and Gravel.—This condition of affairs was only met at Weehawken. Two systems of timbering were used. In the first system, Fig. 17, the ground was excavated 2 ft. 6 in. ahead of the cutting edge, the roof being held by longitudinal poling boards, resting on the outside of the skin at their back end and on vertical breast boards at the forward end. When the upper part of the face was dry, it was held by vertical breast boards braced from the sliding platform and through the shield doors to cross-timbers in the tunnel; the lower part, which was always wet, was held by horizontal breast boards braced through the lower shield pockets to cross-timbers in the tunnel. This system worked all right as long as the ground in the top was sandy enough and had sufficient cohesion to allow the polings to be put in, but, when the upper part was in gravel, thus making it impossible to put in the longitudinal polings or the vertical breasting, the second system came in. Here the excavation was only carried 1 ft. 3 in. (half a shove) ahead of the cutting edge, and the longitudinal polings were replaced by transverse boards supported by pipes which were placed in the holes provided in the shield to accommodate some telescopic poling struts which had been designed but not made. These pipes acted as cantilevers, and were in two parts, a 2½-in. pipe wedged tight into the holes and smaller pipes sliding inside them. After a small section of the ground had been excavated, a board was placed against it, one of the pipes was drawn out under it, and wedges were driven between it and the board. These polings were kept below the level of the hood, so that when the shield was shoved they would come inside of it; in addition, they were braced with vertical posts from the sliding platforms. The upper part of the face was held by longi-

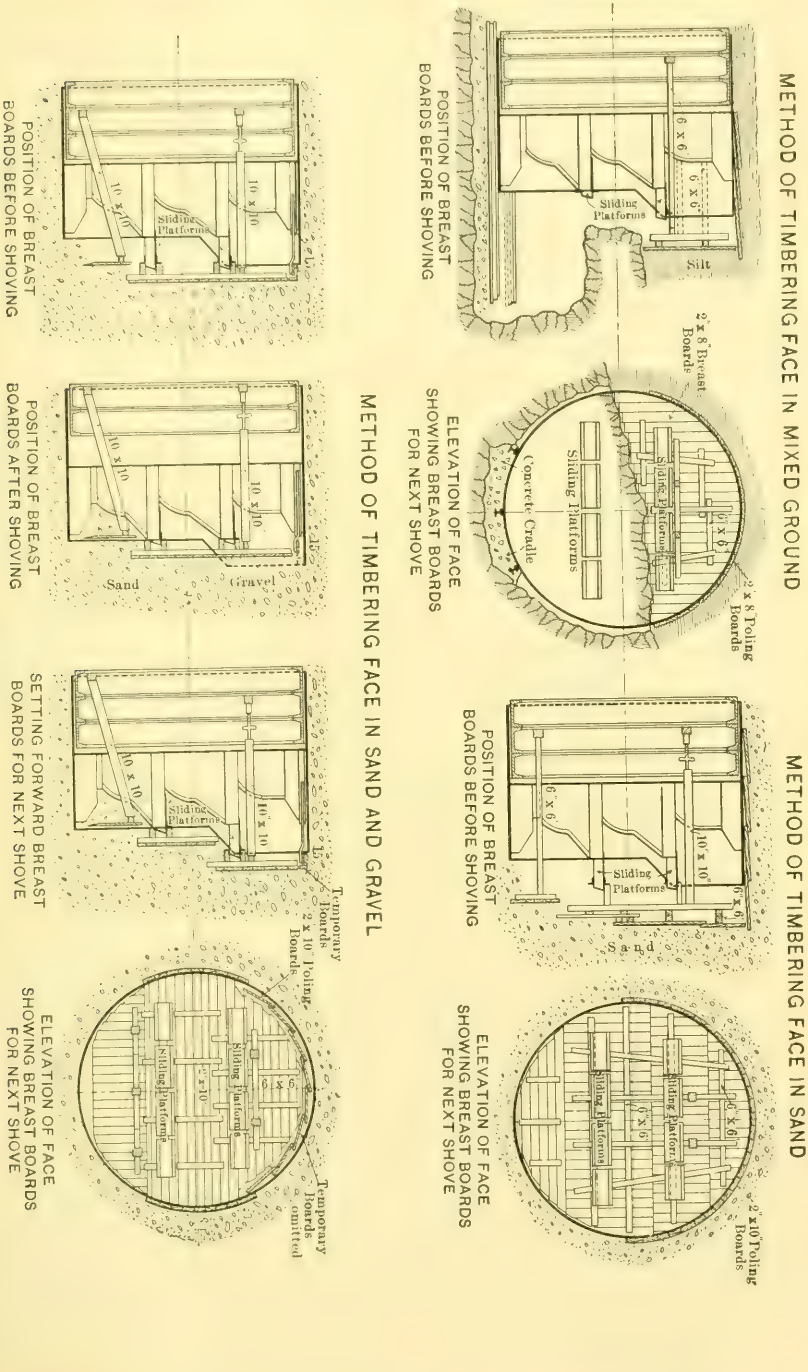

METHOD OF TIMBERING FACE IN MIXED GROUND
6 x 6
6 x 6
Sliding Platforms
Silt
POSITION OF BREAST BOARDS BEFORE SHOVING
2"x 8" Breast Boards
Sliding Platforms
Sliding Platforms
6" x 6"
Concrete Cradle
2"x 8" Poling Boards
ELEVATION OF FACE SHOWING BREAST BOARDS FOR NEXT SHOVE
METHOD OF TIMBERING FACE IN SAND
6" x 6"
10" x 10"
Sliding Platforms
6" x 6"
Sand
POSITION OF BREAST BOARDS BEFORE SHOVING
Sliding Platforms
Sliding Platforms
6" x 6"
6" x 6"
2" x 10" Poling Boards
ELEVATION OF FACE SHOWING BREAST BOARDS FOR NEXT SHOVE
METHOD OF TIMBERING FACE IN SAND AND GRAVEL
10 x 10
10 x 10
Sliding Platforms
POSITION OF BREAST BOARDS BEFORE SHOVING
10 x 10
10 x 10
Sand
Gravel
POSITION OF BREAST BOARDS AFTER SHOVING
10 x 10
Sliding Platforms
10" x 10
Temporary Boards
2" x 10" Poling Boards
SETTING FORWARD BREAST BOARDS FOR NEXT SHOVE
Sliding Platforms
Sliding Platforms
2" x 10"
6 x 6
Temporary Boards omitted
ELEVATION OF FACE SHOWING BREAST BOARDS FOR NEXT SHOVE

Fig. 17.

tudinal breast boards braced from the sliding platform by vertical "soldier" pieces. The lower part of the face was supported by vertical sheet-piling braced to the tunnel through the lower doors. Sometimes two rows of piling were used, but generally one, as shown in Fig. 17. Notwithstanding the fact that the breasting was only 1 ft. 3 in. ahead of the hood, the shield was moved its full stroke of 2 ft. 6 in., the ground around the cutting edge of the hood being scraped away by men working bars in the place from which the temporary breast boards at the circumference had been removed. The back pressure on the sliding platform jacks, when the exhaust valves were only partly open, offered a good deal of resistance, and held the face as long as the movement of the shield was continuous.

On one occasion, when for some reason the shield was stopped with the shove only partly done, and the exhaust valves had not been shut off, the platforms continued to slide and allowed the face to collapse; the shield platforms and doorways, however, caught the falling sand and gravel and the flow choked itself.

As soon as the rock surface was penetrated and the sand and gravel were met, which happened almost at the same time in the two Weehawken Tunnels, the escape of air increased enormously, and it at once became clear that it was impossible to keep enough air in the two tunnels by the methods then in use, even when working the three compressors, each capable of compressing 4 400 cu. ft. of free air per min. at top speed. When the shields just entered the sand and gravel, the face had been held by light breasting, without any special effort to prevent the escape of air, but when it was found impossible to supply enough air, a large amount of straw and clay was used in front of the boards.

This cut down the escape, but, as much air was escaping through the joints of the iron lining, these were plastered with Portland cement. Even then, the loss was too great, therefore one tunnel was shut down entirely and all the air was sent to the other. This allowed a pressure of 10 lb. to be kept up in the working tunnel, and this, though less than the head, was enough to allow progress to be made. In order to use one tunnel as a drain for the other, the two faces were always kept within 150 ft. of each other by working them alternately. The timbered face was never grouted, though this would have reduced the loss of air, as at the same time it would have decreased the progress very much, and any one who saw the racing engines in the power-

house, and realized that a breakdown of one of them would mean the loss of the faces, was ready to admit that the quicker this particular period was cut short, the better.

Above the sand and gravel lay the silt, and, when it showed in the roof, the escape of air was immediately reduced and the two faces could be worked simultaneously. Almost at the same time the piles supporting the large warehouse, known as the Fowler Building, were met. Although the face now took much less timber, the same system of breast boards as had been used in the gravel was kept up, but in skeleton form. They were set 2 ft. 6 in. ahead of the shield, however, instead of 1 ft. 3 in., and the transverse roof poling boards were replaced by longitudinals resting on the shield. The more piles in the face the less timbering was done. The piles were cut into handy lengths with axes and chisels.

All timbering was light compared with the weight of the ground, but, as the shove took place as soon as the set was made, it served its purpose. When a face was closed down the whole system was greatly reinforced by braces from the shield, the face of which was closed by the doors.

In driving through such a face the typical 8-hour shift gang was about as follows:

General:			
⅓ Tunnel superintendent.........	@	$300.00	per month.
1 Assistant tunnel superintendent.	"	5.00	per day.
1 General foreman...............	"	5.00	" "
½ Pipefitter	"	3.25	" "
½ Pipefitter's helper.............	"	2.75	" "
½ Electrician	"	3.00	" "
½ Electrician's helper............	"	2.75	" "
Timbering:			
3 Timbermen	"	2.50	" "
3 Timbermen's helpers...........	"	2.00	" "
Mucking:			
1 Foreman	"	3.50	" "
6 Muckers	"	2.75	" "
Erecting Iron and Driving Shield:			
1 Erector runner.................	"	3.25	" "
1 Foreman	"	4.00	" "
4 Iron workers..................	"	3.00	" "

The drillers were not kept on after the rock disappeared; a foreman was added who divided his time between iron erection and mucking.

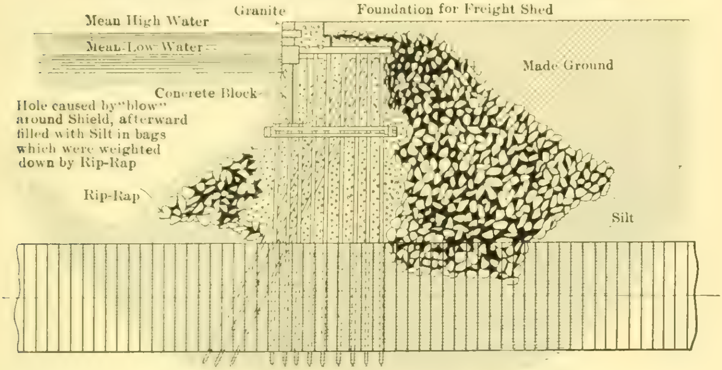
The average rate of progress in sand and gravel without piles was 5.1 ft. per day per shield. When piles and silt were met in the upper part of the face, the speed increased to 7.0 ft. per day.

Passing Under River Bulkhead.—At Weehawken no trouble was found in passing under the river wall, as the bulkhead consisted of only cribwork supported on silt, and, though the piles obstructed the motion of the shield, they were easily cut out, and the cribwork itself was well above the top of the shield.

On the New York side, however, conditions were not nearly as good. The heavy masonry bulkhead was supported on piles and rip-rap, as shown in Fig. 18. The line of the top of the shield was about 6 ft. above the bottom of the rip-rap, the spaces between the stones of which were quite open and allowed a free flow of water directly from the river. As soon, therefore, as the cutting edge of the shield entered the rip-rap there was a blow, the air escaping freely to the ground surface behind the bulkhead and to the river in front of it. Clay puddle, or mud made from the excavated silt, was used in large quantities to plug up the interstices between the stone in the working face, the air pressure being slightly greater than that needed to keep out the water holding it in place. The excavation of the rip-rap was a tedious affair, for it had to be removed one stone at a time and the spaces between the newly exposed stones plugged with mud immediately. One man stood ready with the mud while another loosened the stones with a bar. When the shield had advanced its own length in the rip-rap, another point for the escape of the air was exposed at the rear end of the shield. This loss was closed at the leading end of the last ring with mud and cement sacks.

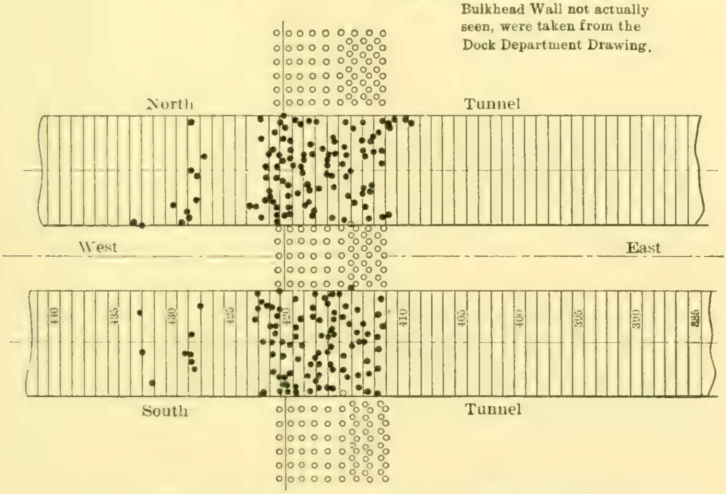
As long as the shield was stationary it was possible, by using these methods and exercising great care and watchfulness, to prevent excessive loss of air; but, while the shield was being shoved ahead, the difficulties were much increased, for the movement of the shield displaced the bags and mud as fast as they were placed, and it was only by shoving slowly and having a large number of men looking out for leaks and stopping them up the instant they developed that excessive loss of air could be prevented. In erecting the iron lining, as each segment was brought into position, it was necessary to clean off the

SKETCH SHOWING RIVER TUNNELS PASSING
UNDER RIVER BULKHEAD WALL AT MANHATTAN



CROSS-SECTION OF RIVER BULKHEAD WALL ON AXIS OF NORTH TUNNEL

Note: The details of the River Bulkhead Wall not actually seen, were taken from the Dock Department Drawing.



PLAN SHOWING PILES REMOVED TO ALLOW PASSAGE OF SHIELD

FIG. 18.

leading surface of the previous ring and the adjacent portion of the tail of the shield; this was always accompanied by a slight "blow," and for some time the air pressure in the tunnel dropped from 25 to 20 lb., that is, from greater than the balancing pressure to less, every time a segment was placed, and on two occasions the "blow" became so great that the tunnel pressure was reduced considerably further, and in consequence the water from the river rushed in and was not stopped until it had risen about 4 ft. in the tunnel invert. On such occasions the surface of the river was greatly disturbed, rising more than 20 ft. in the air in a sort of geyser. A large quantity of grout (about 2 500 bbl. of cement and a similar quantity of sand in the North Tunnel and 1 000 bbl. in the South Tunnel) was used at this point; it was forced through the tunnel lining immediately behind the shield, greatly reducing the loss of air and helping to bind the rip-rap together.

When the shield had traveled 25 ft. through the rip-rap, the piles which support the bulkhead were met. One hundred of these which were spaced at 3-ft. centers in each direction, were cut out of the path of each shield in a distance of 35 ft. The presence of the piles caused considerable extra labor, as each pile had to be cut into several pieces with axes to enable it to be removed through the shield doors, otherwise they presented no difficulties. It was not necessary to timber the face, as the piles supported it most effectively.

When the river line had been passed, the "blow" still continued, and as there was no heavy ground above the tunnel the light silt was carried away into the water by the escaping air. At one time the cover over the crown of the tunnel was reduced to such an extent that for a distance of 30 ft. there was less than 10 ft. of very soft silt, and in some places none at all. Therefore, the shield was stopped and the air pressure reduced until it was less than the balancing pressure; the blow then ceased, and about 28 000 cement bags filled with mud were dumped into the hole (the location made it impossible to dump them *en masse* from a scow). They were then weighted down with rip-rap. This sealed the blow, and the work was continued without any further disturbance from this source. Just before the blow reached its maximum it was found that two of the piles which had been encountered were directly in the path of one of the proposed screw-piles. It was therefore decided to pull these,

and this was done with two 40-ton hydraulic jacks supported by the upper sliding platforms and acting on a horizontal timber which was connected to the piles by tie-rods and chains. The working force here was similar to that employed in the sand and gravel section previously described.

In Full Face of Silt.—A full face of silt was first met under the New York Central Railroad freight yard on the New York side. Up to this point the ground passed through had been either solid rock or a mixed face of rock and gravel. In both of these the full excavation had to be taken out before the shield could be shoved, and the soft ground had needed timbering. When the rock, gravel, and hardpan gave place to a full face of silt, the timber was removed, all the shield doors were opened, and the shield was shoved into the ground without any excavation being done by hand ahead of the diaphragm. As the shield advanced, the silt was forced through the open doors into the tunnel. After the work had gone on in this way for some time, taking in about 90% of the full volume of the tunnel excavation per foot forward, the air pressure was raised from 20 to 22 lb. The result was that the silt in the face got harder and flowed less readily through the shield, and the amount taken in fell to about 65% of the full volume. This manner of shoving at once caused a disturbance on the surface and the railroad tracks above the tunnel were raised, so that the pressure was lowered to 16 lb., then the muck got softer and the full volume of excavation was taken in; after a while the pressure was again raised to 20 lb.

The forcing of the shield through the silt resulted in a rising of the bed of the river, the amount that the bed was raised depending on the quantity of material brought into the shield.

If the whole volume of excavation was being brought in, the surface of the bed was not affected; when about 50% was being taken in, the surface was raised about 3 ft.; if the shield was being driven blind, the bed was raised about 7 ft.

The number of open doors was regulated so as to take in the minimum quantity of muck consistent with causing no surface disturbance. On the average, in the North Manhattan Tunnel, all the doors were open, but in the South Tunnel there were generally only five or six out of the total nine.

In front of the bulkhead wall at Manhattan the tunnels were under

Pier No. 72. This structure was supported on wooden piles, some 80 ft. or more in length, which came down below the tunnel invert. The piles which lay directly in the path of the tunnels, with a few exceptions, had been pulled. In driving the tunnels through this section, great care had to be taken not to disturb the piles on either side of the tunnels, as they supported a heavy trestle used in disposing of the excavation from the open cut in the terminal yard. To avoid such disturbance, a large portion of the total excavation had to be taken through the shields.

The first shield which passed the river bulkhead was the south one at Weehawken. As soon as this line was crossed the silt was found to be much softer than behind the wall, in fact it was like a fluid in many of its properties. The fluidity could be changed by varying the tunnel air pressure; for example, when the air pressure was made equal to the weight of the overlying material (water and silt), the silt was quite stiff, and resembled a rather soft clay; but when the air pressure was from 10 to 15 lb. per sq. in. lower, it became so liquid that it would flow through a 1½-in. grout hole in the lining, in a thick stream, at the rate of from 10 to 50 gal. per min. as soon as the plug was taken out. This was the point to which the contractor had long looked forward, as he expected to be able to close all his shield doors and drive the rest of the way across without taking in a shovelful of muck, as had just been done under the Hudson River, on the South Tunnel of the Hudson and Manhattan Railroad Company's Tunnels between Morton Street, New York City, and Hoboken, N. J. The doors were shut and the shield was shoved; the tunnel at once began to rise rapidly, notwithstanding that the heaviest possible downward leads that the clearance between the iron and the shield would allow were put on. At the same time, the pressures induced in the silt by the shield shouldering the ground aside caused the iron lining to rise about 2 in. as soon as the shield left it, and also distorted it, the horizontal diameter decreasing and the vertical diameter increasing by about as much as 1¼ in. An anxious discussion followed these phenomena, as the effects had been so utterly unexpected, and a good many different theories were advanced as to the probable cause. It was thought that the hood of the shield might have something to do with the trouble. The shield was stopped, the hood removed, the doors were shut, and the driving continued.

The same trouble was found, and it was impossible to keep to grade. Work was stopped, and the question was thoroughly debated; finally, on January 31st, 1906, the chief engineer directed that one of the shield doors be opened as an experiment and 50% of the excavation taken in.

The effect was instantaneous, the shield began to come down to grade at once, and it soon became necessary to close the door partially and reduce the quantity of muck taken in in order to prevent the tunnel from getting below grade. The other troubles from distortion, etc., ceased at the same time.

It was soon found that a powerful aid in the guidance of the shield was thus brought to hand, for, if high, the shield could be brought down by increasing the quantity of muck taken in, if low, by decreasing it. From this time forward, the quantity of muck taken in at each shove was carefully regulated according to the position of the tunnel with regard to grade and the nature of the ground. The quantity varied from nothing to the full volume displaced by the tunnel, and averaged 33% of the latter.

To regulate the flow, the bottom middle door was fitted with two steel angles behind which were placed 6 by 6-in. timbers. In this way the opening could be entirely closed or one of any size left. The muck flowed into the tunnel in a thick stream, as shown in Fig. 2, Plate LXXXIX, and, by regulating the rate of shove, it could be made to flow just as fast as it could be loaded into cars.

In driving through the silt, the typical gang per shift of 8 hours per shield was as follows:

General:

½ Tunnel superintendent..............	@	$300 per month		
1 Assistant tunnel superintendent....	"	6.00	per	day
1 General foreman	"	5.00	"	"
½ Electrician	"	3.50	"	"
½ Electrician's helper.................	"	3.00	"	"
1 Foreman	"	4.00	"	"
2 Pipefitters	"	3.50	"	"
2 Pipefitters' helpers.................	"	3.25	"	"

Mucking:

1 Foreman	"	4.00	"	"
6 Muckers	"	3.00	"	"

Erecting Iron and Driving Shield:

1 Foreman	@ $4.00	per	day
1 Erector runner	" 3.50	"	"
4 Iron workers	" 3.00	"	"
3 Laborers	" 3.00	"	"

Three such shifts were worked per day and the air pressure averaged 25 lb. per sq. in.

The increase in the number of pipefitters was due to the greatly increased speed, and also the steadily increasing length of completed tunnel. The three laborers in the erection gang spent their whole time tightening bolts. The rate of progress in the silt under the river per ring of 2½ ft. was 3 hours 21 min., exclusive of all time when work was actually suspended. For a considerable part of the time only two 8-hour shifts were worked, owing to a shortage of iron caused by the change in the design of the lining, whereby the original lining was changed to a heavier one, and, as the work was also stopped for experiments and observations, the average of the actual total time, including all the time during which work was suspended, was 5 hours 32 min. per ring, or 10.8 ft. per day.

The junction of the shields under the river was made as follows: When the two shields of one tunnel, which had been driven from opposite sides of the river approached within 10 ft. of each other, the shields were stopped, a 10-in. pipe was driven between them, and a final check of lines and levels was made through the pipe. Incidentally, also, the first through traffic was established by passing a box of cigars through the pipe from the Manhattan shield to that from Weehawken. One shield was then started up with all doors closed while the doors on the stationary shield were opened so that the muck driven ahead by the moving shield was taken in through the other one's doors. This was continued until the cutting edges came together. All doors in both shields were then opened and the shield mucked out. The cutting edges were taken off, and the shields moved together again, edge of skin to edge of skin. The removal of the cutting edge necessitated the raising of the pressure to 37 lb. As the sections of the cutting edges were taken off, the space between the skin edges was poled with 3-in. stuff. Fig. 1, Plate XCIII, is a view of the shields of the North Tunnel after being brought together and after parts of the interior frames had been removed. When

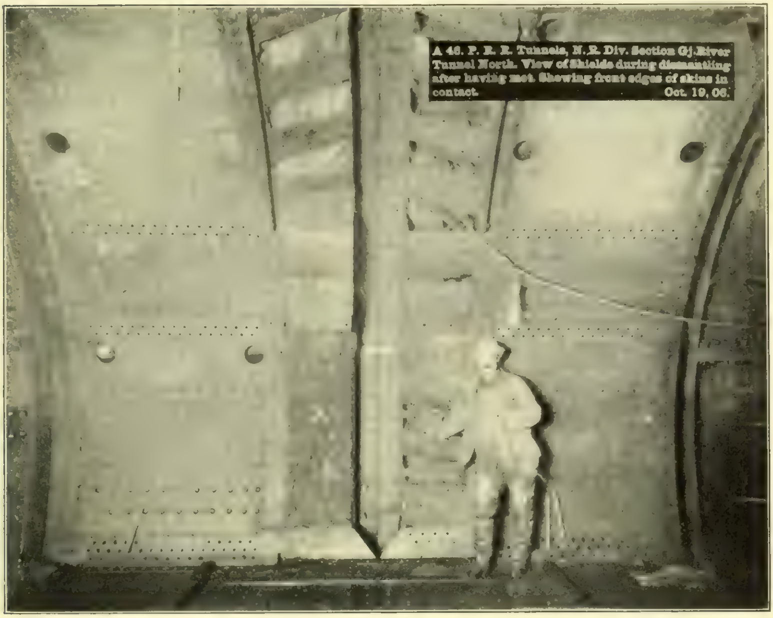

A 46. P. R. R. Tunnels, N. R. Div. Section Gj. River Tunnel North. View of Shields during dismantling after having met. Showing front edges of skins in contact.
Oct. 19, 06.

FIG. 1.


A 40. P. R. R. Tunnels, N. R. Div. Sect. Gj. River Tunnel, (South) Weehawken, lowering segment into invert of tunnel.
Aug. 30, 06.

FIG. 2.

everything except the skins had been removed, iron lining was built up inside the skins, the gap at the junction was filled with concrete, and long bolts were used from ring to ring on the circumferential joint. Finally, the rings inside the shield skins were grouted.

In order to make clear the nature of the work done in building these shield-driven tunnels in silt, a short description will be attempted, this description falling into three main divisions, namely, Shoving the Shield, Pushing Back the Jacks, and Erecting the Iron Lining.

Shoving the Shield.—This part of the work is naturally very important, as the position of the shield determines within pretty narrow limits the position of the iron built within it, hence the shield during its forward movement has to be guided very carefully. On this work certain instructions were issued for the guidance of the foreman in charge of the shield. These instructions were based on results of "checks" of the shield and iron's position by the engineering corps of the Company, and comprised, in the main, two requirements, namely, the leads that were to be got, and the quantity of muck to be taken in. The "lead" is the amount that the shield must be advanced further from the iron, on one side or the other, or on the top or bottom, as measured from the front face of the last ring of iron lining to the diaphragm of the shield. These leads are not necessarily true leads from a line at right angles to the center line, as the iron may have, and in fact usually does have, a lead of its own which is known and allowed for when issuing the requirements for the shove.

The foreman, knowing what was wanted, arranged the combination of shield jacks which would give the required leads and the amount of opening on the shield door which would give the required amount of muck. To see how the shield was going ahead, a man was stationed at each side at axis level and another in the crown. Each man had a graduated rod on which the marks were so distinct that they could be read by anyone standing on the lower platform. These rods were held against the shield diaphragm, and, as it advanced, its distance from the leading end of the last ring could be seen by the man in control of the jack valves. If he found that he was not getting the required leads, he could change the combination of jacks in action. As the time of a shove was often

less than 10 min., the man had to be very quick in reading the rods and changing the jacks. If it was found that extensive change in the jack arrangement was wanted, the shove could be stopped by a man stationed at the main hydraulic control valve; but, as any such stoppage affected the quantity of muck taken in, it was not resorted to unless absolutely necessary.

If the quantity of muck coming in was not as desired, a stop had to be made to alter the size of the opening, and if, while this was being done, the exhaust valves were not closed quite tight, the silt pressure on the face of the shield would force it back against the iron. This fact was sometimes taken advantage of when a full opening did not let in the desired quantity, for the shield could be shoved, allowed to return, and shoved again.

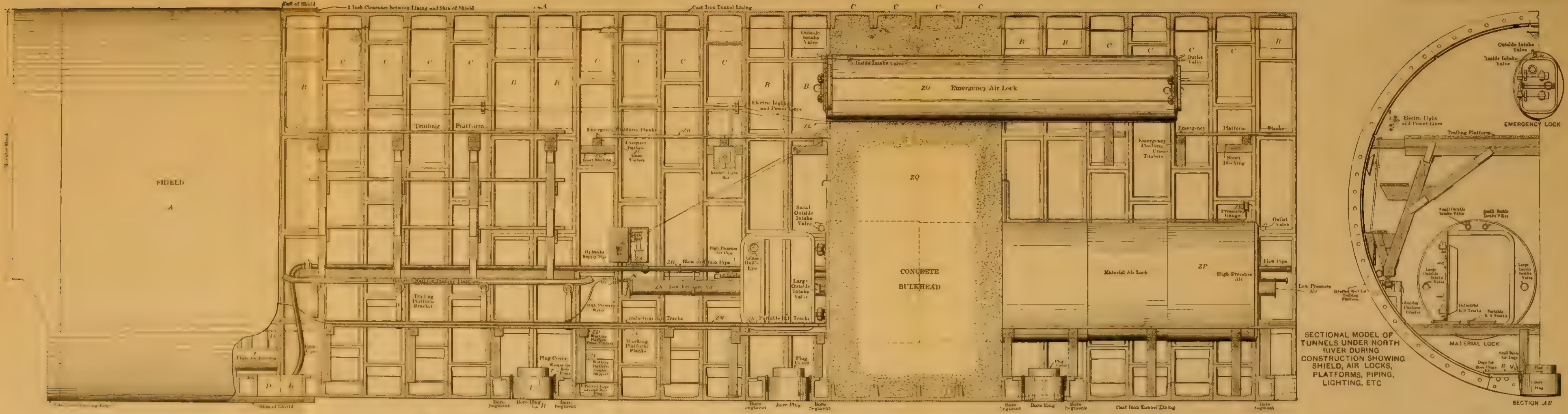
The time taken to shove in silt varied greatly with the quantity of material taken in; for shoving and mucking combined, it averaged 66 min., with an average of 13 cu. yd. of muck disposed of, or about 5 min. per cu. yd. of material.

Pushing Back the Jacks.—This was a simple matter, and merely consisted in making the loose push-back connection to each jack as it had to be sent back. Some of the jacks became strained and bent, and had to be taken out and replaced. Where there was silt pressure against the face of the shield, the hydraulic pressure had to be kept on until the ring was erected. In such cases, only two or three jacks could be pushed back at a time, and only after a segment had been set in position, and the pressure taken on it, could the next jack be pushed back, and so on around the ring. The time between the finish of the shove (hydraulic pressure turned off) and the placing of the first segment, was occupied in pushing back the bottom jacks and cleaning dirt off the tail of the shield, and averaged about 14 min.

Erecting the Iron Lining.—As soon as the shove was over, the whole force, when in silt, set to work at building up the iron and then tightening the bolts so that the shield could be shoved again. A section of the tunnel with bolting and working platform is shown on Plate XCIV.

In the early part of the work, when the ground was being excavated ahead of the shield, the whole force, with the exception of those working in front of the shield, was engaged in erecting the

PLATE XCIV.
PAPERS, AM. SOC. C. E.
APRIL, 1910.
HEWETT AND BROWN ON
PENN. R. R. TUNNELS: THE NORTH RIVER TUNNELS.



SECTIONAL MODEL OF TUNNELS UNDER NORTH RIVER DURING CONSTRUCTION SHOWING SHIELD, AIR LOCKS, PLATFORMS, PIPING, LIGHTING, ETC

iron, but, as soon as this was done, most of the men returned to the mucking, and only the iron workers continued to tighten up bolts. On the other sections, where the shield was shoved into the silt without excavating ahead, as soon as the shove was completed, the whole force was engaged in the erection of the iron and the tightening of the bolts, until they were so tight that the shield could be shoved again for another ring.

The iron was brought into the tunnel on flat cars, two segments to the car, and was lifted from the car and lowered into the invert of the shield by a block and fall and chain sling, as shown in Fig. 2, Plate XCIII. The bottom three or four segments were pushed around into position with the erector, the head simply bearing against the longitudinal flange without being attached to the segment; the upper segments, however, were, as shown in Fig. 2, Plate XCII, and Fig. 1, Plate XCV, attached to the erector, by using the expanding bar and the erector head designed by Mr. Patrick Fitzgerald, the Tunnel Superintendent. This was found to be a most convenient arrangement.

The single erector attached to the center of the shield was able to erect the iron as fast as it could be brought into the tunnel, and even when the weight of the segments was increased 25% (from 2 060 to 2 580 lb.) it always proved equal to its task, although occasionally one of the chains in the mechanism broke and delayed the work for an hour or so; but the sum of all the delays from this cause and from breaks and leaks in the hydraulic line only averaged 13 min. per ring. The operating valve which was first used was a four-spindle turning valve, but this was replaced by a sliding valve which was found to be much more satisfactory, both in ease of operation and freedom from failure.

As the iron was put into place, two of the middle bolts in each longitudinal flange and two in each circumferential one were pulled as tight as possible, and the others put in loosely; then, as soon as the ring was in position, as large a force as could be conveniently worked at one time was engaged in tightening the bolts. The shape of the tunnel depended on the thoroughness of the tightening of the bolts, and the shield was never shoved until the bolts in all the longitudinal flanges had been thoroughly tightened. In addition, all the bolts in the circumferential flanges below the axis were tightened,

and at least three of the six in each segment above. After the shield had been shoved ahead, the bolts were found to have slackened, and, where the daily progress was four rings, or more, it was necessary to have a small gang of men always at this work.

In order to get at the bolts, special platforms were necessary, and throughout the greater part of the work, a traveling platform was used. This enabled the men to reach handily all parts of the seven leading rings. This platform was supported and moved forward on wheels fixed on brackets to the tunnel, and was pulled forward by connecting chains every time the shield was shoved. In the early part of the work it was not possible to use platforms, because, in order to maintain the correct circular shape of the iron lining, it was necessary to put in temporary horizontal turnbuckles at axis level. These, however, were very convenient for supporting the planks which were used as a temporary bolting platform for the sides of the tunnel, and a temporary platform resting on 6 by 6-in. timbers across the tunnel enabled the bolts in the crown of the tunnel to be reached, while the 6 by 6-in. timbers were left in to support the emergency platform previously described (Plate XCIV), which extended the entire length of the tunnel.

The time taken to erect the iron lining became shorter and shorter as the tunnel organization became more perfect and the force better trained, so that, whereas, in the early part of the work, it frequently took 6 hours to erect a ring, in the latter part, when the work was nearing completion, it was a common occurrence to erect a ring in 30 min. The average time in the "heavy iron" section, which included the greater part of the work under the river, was 1 hour 4 min. for the erection of the ring and 40 min. for tightening the bolts after that had been completed, so that the total time spent by the whole gang on erection and bolting averaged 1 hour 44 min. per ring, exclusive of the time spent by the small gang which was always engaged in tightening the bolts. The average time spent in erecting and bolting, for the whole length of the tube tunnels, was 2 hours 15 min. per ring.

Tables of Progress.—Tables 24, 25, 26, and 27 have been prepared to show the time taken in the various operations at each working face.


A 45. P. R. R. Tunnels. N. R. Div. Section Gy West.
South Manhattan. Fitting in key seg-
ment. Sept. 11, 06.

FIG. 1.


A 132. P. R. R. Tunnels, N. R. Div. Sect. Gy West (South Tunnel).
Method of grouting outside iron lining. May 12, 09.

FIG. 2.

In Tables 24, 25, 26, and 27, the following symbols are used:

A—Including assistant superintendents, foremen, and electricians, in driving the shield, erecting iron, mucking, attending to the electric lights, and repairing the pipe line.

B—Drillers, drillers' helpers, drill foremen, and nippers.

C—All men grouting.

D—Engineers and laborers wholly employed on transport between the first lock and the face.

E—In rock, one car = 0.60 cu. yd.; in sand or silt = 1.20 cu. yd. in place.

F—Time between completion of mucking and putting in first plate, spent in shoving the jacks back.

G—In ordinary iron = the whole time spent on erection and bolting. In heavy iron = the time between putting in the first plate and placing the key only.

H—Time between placing the key and starting the next shove, spent by the whole gang in tightening bolts. In addition to this, there was a small gang which spent its whole time at this work.

I—In Table 24 the first pair of bore segments is at ring 207-208.
" " 25 " " " " " " " " " 201-202.
" " 26 " " " " " " " " " 185-186.
" " 27 " " " " " " " " " 171-172.

Outside diameter of tunnel = 23 ft. 0 in.
Inside " " " = 21 ft. 2 in.
Length of ring = 2 ft. 6 in.

In the "Ordinary Iron" section the time is divided between mucking (which included the shoving and pushing back of the jacks) and the erection time (which included the time spent by the whole gang in tightening bolts). In the "Heavy Iron" section these times are all separated into "Mucking," "Pushing Back Jacks," "Erecting," and "Bolting," and here the bolting time included only that spent on bolts by the whole gang; in addition, there was a small gang engaged solely in tightening bolts. The lost time is the average time lost due to the break-down of hydraulic pipe lines, damaged jacks, and broken erector chains. The erection time is separated for the various kinds of rings, that is, straight ordinary rings, rings con-

TABLE 24.—SHIELD-DRIVEN TUNNEL WORK,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Ave. air pressure.	Method of excavation.	Ave. No. of Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Av. No. of cu. yd. per ring. E	Time mucking, per cu. yd.
Ordinary.	1-54	135.0	Rock	0	‡	....	....	....	....	14	....	....
	55-80	65.0	"	19	‡	24	7	$\frac{1}{3}$	1	32	41	0-31
	81-106	65.0	Soft rock	18	‡	22	5	....	2	29	41	0-33
	107-153	117.5	Rock	14	‡	17	11	....	2	30	41	0-39
	154-194	102.5	Rock and earth	14	‡	23	6	....	2	31	41	0-27
	195-215	52.5	Silt	19	‡ Breasting	28	....	....	2	30	41	0-10
	216-393	445.0	"	20	§ 8 doors	27	....	....	4	31	46	0-5
	394-429	90.0	Silt, piles, rip-rap.	24	‡ Breasting	28	....	....	4	32	46	0-18
	430 509	200.0	Silt	23	§ 1 door	24	....	....	3	27	11	0-10
	510-692	457.5	"	23	§ 3 doors	26	....	....	4	30	20	0-5
	55-692	1 595.0	....	20	....	25	2	....	3	30	30	0-15
	216-692	1 192.5	....	22	....	26	....	....	4	30	30	0-07
Heavy.	693-954	655.0	Silt	24	§ 1 door	28	....	....	6	34	11	0-12
	955-1 014	150.0	"	24	§ 1 "	28	....	....	8	36	12	0-4
	1 015-1 074	150.0	"	24	§ 1 "	25	....	....	8	33	12	0-3
	1 075-1 134	150.0	"	24	§ 1 "	27	....	....	9	36	8	0-4
	1 135-1 194	150.0	"	25	§ 1 "	26	....	....	8	34	8	0-4
	1 195-1 224	75.0	"	25	§ 1 "	24	....	....	9	33	6	0-4
	1 225-1 262	95.0	"	25	§ 1 "	23	....	....	9	32	5	0-5
	1 263-1 277	37.5	"	25	§ 1 "	24	....	....	10	34	10	0-4
	1 278-1 307	75.0	"	25	§ 1 "	21	....	....	10	31	17	0-4
	1 308-1 326	47.5	"	28	§ 1 "	27	....	....	11	38	22	0-5
	955-1 326	930.0	....	24	....	26	....	....	9	35	11	0-4
	693-1 326	1 585.0	....	24	....	27	....	....	8	35	12	0-4
All.	216-1 326	2 777.5	....	23	....	27	....	....	7	34	19	0-6
	55-1 326	3 180.0	....	22	....	26	....	....	6	32	21	0-10

SUM

Weight of iron.	Section between rings.	Description. Length, in feet.	Material.	Ave. air.	Method of excavating.	Average No. of Men in Gang. Shield.	Drilling.	Grouting.	Air Trans.	Total.
Ordinary.	1-54	135.0	Rock	0	‡	......	......	....	......	14
	55-194	350.0	Earth and rock.	16	‡	22	6	$\frac{1}{3}$	2	30
	195-393	497.5	Silt	20	‡ Breasting.	27	......	....	4	31
	394-440	117.5	"	24	‡ Breasting.	28	......	....	4	32
	441-692	630.0	"	23	§ 3 doors	25	......	....	4	29
	216-692	1 192.5	....	22	....	26	......	....	4	30
	55-692	1 595.0	....	20	....	25	2	....	3	30
Heavy.	693-1 326	1 585.0	Silt	24	§ 1 door	27	......	....	8	35
All	55-1 326	3 180.0	....	22	....	26	......	....	6	32

* Including time for jacks. † Including bolting time. ‡ Excavating ahead of shield.

MANHATTAN SHAFT, RIVER TUNNEL NORTH.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Av. time per ring, shoving and mucking.	Time for jacks.	Time for Ring Erection, Hrs. and Min.					Bolting Time, Whole Time on Bolts After Ring is Complete.					Time lost repairing hydraulic piping.	Total Time.				
		Ordin'ry.	Bore 1.	Bore 2.	Taper.	Mean.	Ordin'ry.	Bore 1.	Bore 2.	Taper.	Mean.		Ordinary.	Bore 1.	Bore 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
......	Time for jacks for light iron is included in shoving and mucking.	4-0	....	....	4 21	4-4	Excavation partially completed previously.										
21-0		6-4	....	....	5-30	5-57						......	27-4	.....	.....	26-30	26-57
22-30		4-26	....	....	....	4-26						......	26-56	.....	.....	.....	26-56
26-31		3-10	....	....	3-30	3-12						......	29-41	.....	.....	30-1	29-43
18-34		2-08	J.	J.	2-40	2-10						......	20-42	.....	.....	21-14	20-44
6-46		3-03	3-30	3-30	....	3-09						......	9-49	10-16	10-16	.....	9-55
3-53		2-40	2-56	3-00	3-10	2-50						0-9	6-42	6-58	7-02	7-12	6-52
17-09		3-43	3-39	4-46	4-11	3-56	Bolting time for light iron is included in erection.					2-37	23-79	23-25	24-32	23-57	23-42
1 42		3-14	4-12	3-59	3-46	3-34						0-18	5-14	6-12	5-59	5-46	5-34
1 47		2-08	2-21	2-32	2-50	2-18						0-11	4-06	4-19	4-30	4-48	4-16
7 35	*	3-02	....	....	4-31	3-12						0-17	10-54	.....	.....	12-23	11-04
3-42	*	2-38	2-59	3-08	1-30	2-50						0-25	6-45	7-06	7-15	5-37	6-57
1-02	*	1-52	2-05	2-15	2-29	2-0						0-13	3-7	3-20	3-30	3-44	3-15
0-48	0-16	0-51	1-18	1-8	0-50	0-58	0-24	0-21	0-37	0-10	0-25	0	2-19	2-43	2-49	2-04	2-27
0-41	0-13	0-43	0-46	0-55	0-40	0-45	0-31	0-30	0-52	0-23	0-34	0-2	2-10	2-12	2-43	1-59	2-15
0-34	0-12	1-4	1-1	1-15	1-20	1-08	0-28	0-35	1-40	0-52	0-44	0-3	2-21	2-25	3-44	3-01	2-41
0-33	0-13	0-53	0-51	0-58	0-46	0-53	0-32	0-20	0 24	0-18	0-26	0	2-11	1-57	2-08	1-50	2-05
0-24	0-12	0-58	0-42	0-53	0-50	0-54	0-19	0-20	0-34	0-35	0-23	0	1-53	1-38	2-03	2-01	1-53
0-23	0-10	0-48	0-49	0-50	0-35	0-47	0-29	0-29	0-36	0-18	0-30	0	1-50	1-51	1-59	1-26	1-50
0-36	0-11	0-47	0-50	0-52	0-48	0-52	0-23	0-23	0-41	0-23	0-27	0	1-57	2-0	2-20	1-58	2-06
1-09	C-10	1-3	1-01	1-06	0-0	1-04	0-33	0-34	0-51	0-0	0-36	0	2-55	2-54	3-16	0-0	2-59
1-39	0-18	1-25	1-48	1-50	0-50	1-31	0-49	0-42	0-58	0-25	0-48	0	4-11	4-27	4-45	3-12	4-16
0-41	0-13	0-55	0-59	1-03	0-55	0-58	0-29	0-27	0-49	0-31	0-32	0	2-18	2-20	2-46	2-20	2-24
0-51	*	1-27	1-34	1-41	1-38	1-31	†	....	....	....	....	0-6	2-24	2-31	2-38	2-35	2-28
1-59	*	1-55	2-08	2-16	1-35	2-03	†	....	....	....	....	0-16	......	.....	.....	.....	4-18
4-13	*	....	....	....	....	2-22	†	....	....	....	....	0-12	......	.....	.....	.....	6-47

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring.				Unavoidable Delays (not Included in Average Time per Ring).		
		Shoving and mucking. *	Erection. †	Lost time.	Total.	Items.	Time. hrs.	min.
....	....	....	4-14	....	....	First bulkhead............	172	00
41	0-32	21-44	4-4	....	25-48	Second bulkhead...... ...	119	00
38	0-7	4-11	2-52	0-9	7-12	Grouting..................	200	00
41	0-18	11-54	4-17	1-41	17-52	Blowout..................	73	00
17	0-6	2-04	2-34	0-42	5-20	Cradle....................	100	00
30	0-7	3-42	2-50	0-25	6-57	Total..................	664	00
30	0-15	7-35	3-12	0-17	11-04	Per ring.............	0	30
12	0-4	0-51	1-31	0-06	2-28			
21	0-10	4-13	2-22	0-12	6-47			

§ Shoving shield into slit with....doors open.

TABLE 25.—SHIELD-DRIVEN TUNNEL WORK,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Av. air pressure.	Method of excavation.	Average No. Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Av. No. of cu. yd. per ring. E	Time mucking, per cu. yd.
Ordinary.	1–68	170.0	Rock..............	0	*	20	5	5	2	32	41	0–14
	69–95	67.5	Rock and earth...	13	*	22	8	....	2	32	41	0–24
	96–141	115.0	Rock..............	10	*	21	13	....	2	36	70	0–16
	142–191	125.0	Rock and earth...	15	*	24	7	....	2	33	52	0–20
	192–203	30.0	Silt..............	18	*Breasting.	23	....	....	3	26	36	0–13
	204–388	462.5	"	18	†7 doors.	27	....	....	3	30	37	0–05
	389–429	102.5	Silt, piles and rip-rap.......	22	†6 doors. *Breasting.	24	....	....	4	28	40	0–17
	430–504	187.5	Silt..............	21	†3 doors.	23	....	....	5	28	20	0–06
	505–629	312.5	"	22	†4 doors.	25	....	....	6	31	27	0–05
	630–692	157.5	"	23	†2 doors.	24	....	....	8	32	22	0–05
	204–692	1 222.5	....	21	....	25	....	....	5	30	30	0–07
	69–692	1 560.0	....	17	....	23	4	0	3	30	36	0–11
Heavy.	693–766	185.0	Silt..............	24	†2 doors.	21	....	....	6	27	22	0–05
	767–806	100.0	"	24	†2 "	22	....	....	7	29	22	0–05
	807–900	235.0	"	24	†1½ doors.	23	....	....	8	31	19	0–05
	901–933	82.5	"	25	†1 door.	30	....	....	10	40	19	0–04
	934–988	137.5	"	25	†1 "	30	....	....	11	41	16	0–04
	989–1 043	137.5	"	25	†1 "	28	....	....	11	39	13	0–05
	1 044–1 053	25.0	"	26	†1 "	25	....	....	9	34	16	0–07
	1 054–1 068	37.5	"	26	†1 "	26	....	....	9	35	8	0–05
	1 069–1 110	105.0	"	26	†1 "	30	....	....	11	41	13	0–06
	693–1 110	1 045.0	....	25	....	25	....	....	8	33	18	0–05
All.	204–1 110	2 267.5	....	23	....	25	....	....	6	31	25	0–06
	69–1 110	2 605.0	....	20	....	24	2	....	5	31	29	0–09

SUM

Weight of iron.	Section between rings.	Description. Length, in feet.	Material.	Av. air pres.	Method of excavation.	Average No. of Men in Gang. Shield.	Drilling.	Grout-ing.	Air trans.	Total.
Ordinary.	1–68	170.0	Rock............	0	*............	20	5	5	2	32
	69–191	307.5	Rock and earth..	13	*............	22	9	....	2	33
	192–388	492.5	Silt..............	18	*Breasting. †7 doors....	25	......	....	3	28
	389–429	102.5	Silt, piles and rip-rap.	22	*Breasting.. †6 doors....	24	......	....	4	28
	430–692	657.5	Silt..............	22	†3 doors....	24	......	....	6	30
	204–692	1 222.5	....	21	....	25	......	....	5	30
	69–692	1 560.0	....	17	....	23	4	0	3	30
Heavy.	693–1 110	1 045.0	....	25	†1 door	25	......	....	8	33
All.....	69–1 110	2 605.0	....	20	....	24	2	....	5	31

* Excavating ahead of shield. † Shoving shield into silt with.....doors open.

MANHATTAN SHAFT, RIVER TUNNEL SOUTH.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Av. time per ring, shoving and mucking.	Time for jacks.	Time for Ring Erection. Hrs. and Min. Ordin.	Bore 1.	Bore 2.	Taper.	Mean.	Bolting Time, Whole Time on Bolts After the Ring is Complete. Ordin.	Bore 1.	Bore 2.	Taper.	Mean.	Time lost repairing hydraulic fitting.	Total Time. Ordin.	Bore 1.	Bore 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
9-53		5-27	....	....	4-32	5-07	Excavation partially completed previously.					....	15-20	......	......	14-25	15-00
16-18	Time for jacks for light iron is included in shoving and mucking.	3-02	....	....	2-40	3-00						....	19-20	......	......	18-58	19-18
18-16		2-08	....	....	2-27	2-09						0-03	20-27	......	......	20-46	20-28
17-27		2-08	J	J	2-04	2-08						0-12	19-47	......	......	19-43	19-47
7-58		2-27	6-00	2-10	3-15	2-47	Bolting time for light iron is included in erection.					1-20	11-45	15-18	11-28	12-33	12-05
3-19		2-41	2-49	2-54	2-56	2-47						0-05	6-05	6-13	6-18	6-20	6-11
12-42		3-15	2-36	5-03	3-26	3-27						0-38	16-35	15-56	18-23	16-46	16-47
1-51		2-53	3-17	3-00	2-57	2-59						0-39	5-23	5-47	5-30	5-27	5-29
2-20		2-23	2-40	2-45	2-28	2-30						0-23	5-06	5-23	5-28	5-11	5-13
1-53		1-54	2-10	2-22	2-23	2-02						0-08	3-55	4-11	4-23	4-24	4-03
3-27	‡	2-34	2-45	2-58	2-35	2-42						0-18	6-19	6-30	6-43	6-20	6-27
6-40	‡	2-47	....	....	3-18	2-52						0-15	9-42	......	......	10-13	9-47
1-35	0-25	1-18	1-44	1-30	1-40	1-25	0-43	1-09	0-52	0-50	0-49	0-07	4-08	5-00	4-29	4-37	4-21
1-19	0-21	1-00	0-56	1-37	1-21	1-08	0-38	0-24	0-43	0-38	0-42	0-02	3-20	3-02	4-02	3-41	3-32
1-11	0-17	0-58	1-13	1-08	1-12	1-04	0-39	0-34	0-56	0-31	0-40	0-06	3-11	3-21	3-38	3-17	3-18
1-13	0-09	0-59	1-05	0-59	....	1-00	0-34	0-26	1-47	....	0-43	0-05	3-00	2-58	4-13	.....	3-10
0-54	0-12	0-49	0-44	0-56	....	0-50	0-28	0-34	0-34	....	0-30	0-06	2-29	2-30	2-42	.....	2-32
0-52	0-14	0-51	0-44	0-52	1-14	0-52	0-33	0-24	0-51	0-35	0-35	0-04	2-34	2-18	2-53	2-59	2-37
1-40	0-15	1-04	1-15	0-50	0-55	1-02	0-23	0-38	0-30	0-55	0-36	....	3-22	3-48	3-15	3-45	3-33
0-36	0-08	0-57	0-40	1-02	....	0-56	0-33	0-25	0-35	....	0-32	....	2-14	1-49	2-21	.....	2-12
1-00	0-15	0-48	0-54	1-06	1-31	0-56	0-32	0-40	0-48	0-46	0-37	0-05	2-40	2-54	3-14	3-37	2-53
1-29	‡	1-01	1-08	1-09	1-19	1-05	0-37	0-39	0-52	0-40	0-40	0-05	3-12	3-21	3-35	3-33	3-19
2-35	‡	2-09	2-19	2-33	2-19	2-17	§	....	....	....	....	0-12	4-56	5-06	5-20	5-06	5-04
4-36	‡	2-19	....	....	2-46	2-25	§	....	....	....	....	0-14	7-09	......	......	7-36	7-15

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring. Shoving and mucking. ‡	Erection. §	Lost time.	Total.	Unavoidable Delays (not Included in Average Time per Ring). Items.	Time. hrs.	min.
41	0-14	9-53	5-07	....	15-00	First bulkhead............	160	00
54	0-19	17-20	2-26	0-05	19-51	Second bulkhead..........	157	45
37	0-09	5-39	2-47	0-63	9-29	Grouting..................	264	00
40	0-17	12-42	3-27	0-38	16-47	Blowout....................	69	45
24	0-05	1-58	2-29	0-22	4-49	Waiting for heavy iron....	64	00
30	0-07	3-27	2-42	0-18	6-27	Total..................	715	30
36	0-11	6-40	2-52	0-15	9-47	Per ring..............	0	39
18	0-05	1-29	1-45	0-05	3-19			
29	0-09	4-36	2-25	0-14	7-15			

‡ Including time for jacks. § Including bolting time.

TABLE 26.—SHIELD-DRIVEN TUNNEL WORK,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Ave. air pressure.	Method of excavation.	Ave. No. of Men in Gang. Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	Ave. No. of cu. yds. per ring. E	Time mucking, per cu. yd.
Ordinary.	1-24	60	Rock....................	0	‡	9	0.04	0	0	10	46	0-06
	25-55	77.5	"	20	‡	14	5	0.5	1	21	46	0-51
	56-72	42.5	Mixed sand and rock...	10	‡ Breast'g.	22	2	0.09	2	26	44	0-21
	73-165	232.5	Sand and gravel.........	10	"	22	0	0.1	2	24	39	0-11
	166-184	47.5	Sand and silt with piles.	20	‡Breast'g and cutting piles	22	0	0.38	3	25	42	0-09
	185-253	172.5	Silt and piles............	24		23	0	0.71	3	26	43	0-09
	254-293	100.0	Silt.....................	26	§ 8 doors...	22	0	0	3	25	6	0-18
	294-301	20.0	"	27	....	19	0	0	2	21	0	0
	302-307	15.0	"	27	§ 8 doors...	21	0	0	2	23	26	0-09
	308-342	87.5	"	28	....	19	0	0	2	21	0	0
	343-347	12.5	"	28	§ 8 doors...	15	0	0	2	17	2	0-36
	348-459	280.0	"	28	....	20	0	0	3	23	0	0
	460-494	87.5	"	28	§ 8 doors...	21	0	0	3	24	9	0-09
	495-513	47.5	"	28	8 "	23	0	0	4	27	17	0 05
	514-605	230.0	"	28	8 "	25	0	0	4	29	26	0-04
	606-624	47.5	"	28	8 "	24	0	0	4	28	16	0-04
	625-640	40.0	"	28	8 "	38	0	0	5	43	24	0-03
	25-640	1 540.0	....	20	....	..	....	....	..	..	....	....
	185-640	1 140.0	....	26	....	23	0	0.2	3	26	16	0-07
Heavy.	641-647	17.5	Silt.....................	28	§ 8 doors..	24	0	0	6	30	19	0-04
	648-751	260.0	"	28	§ 8 " ..	22	0	0	4	26	14	0-03
	752-795	110.0	"	28	§ 8 " ..	18	0	0	7	25	10	0-03
	796-825	75.0	"	28	§ 8 " ..	19	0	0	10	28	5	0-08
	826-854	72.5	"	28	§ 8 " ..	17	0	0	3	20	15	0-03
	855-881	67.5	"	28	§ 8 " ..	23	0	0	9	32	7	0-05
	882-982	252.5	"	28	§ 8 " ..	20	0	0	8	28	10	0-02
	983-990	20.0	"	28	§ 8 " ..	21	0	0	7	28	17	0-02
	991-1 049	147.5	"	28	§ 8 " ..	23	0	0	7	30	8	0-03
	1 050-1 074	62.5	"	28	§ 8 " ..	24	0	0	9	33	7	0-03
	1 075-1 110	90.0	"	28	§ 8 " ..	25	0	0	10	35	16	0-02
	641-1 110	1 175.0	....	28	....	21	0	0	7	28	8	0-04
All.	185-1 110	2 315.0	....	28	....	22	0	0.1	5	27	12	0-07
	25-1 110	2 715.0	....	26	....	21	0.1	0.1	3	24	17.1	0-12

SUM

Weight of iron.	Section between rings.	Description. Length in feet.	Material.	Ave. air.	Method of excavation.	Average No. of Men in Gang. Shield.	Drilling.	Grouting.	Air trans.	Total.
Ordinary.	1-24	60.	Rock	0	‡	9	0.04	0	0	10
	25-55	77.5	"	20	‡	14	5	0.5	1	21
	56-72	42.5	Mixed sand and rock...........	10	‡Breasting.	22	2	0.09	2	26
	73-165	232.5	Sand and gravel.	10	‡Breasting.	22	0	0.1	2	24
	166-184	47.5	Sand and silt with piles.	20	‡Breasting and cutting piles.	22	0	0.38	3	25
	185-253	172.5	Silt with piles...	24		23	0	0.71	3	26
	254-640	100.0	Silt	26	§Doors.....	22	0	0	3	25
	25-640	1 540.0	....	20	§Doors.....	21	0.3	0.12	3	24
Heavy.	641-1 110	1 175.0	....	28	....	21	0	0	7	28
All....	25-1 110	2 715.0	....	26	....	21	0.1	0.1	3	24

* Including time for jacks. † Including bolting time.

WEEHAWKEN SHAFT, RIVER TUNNEL NORTH.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Av. time per ring, shoving and mucking.	Time for jacks.	Time for Ring Erection. Hrs. and Min.					Bolting Time, Whole Time on Bolts After Ring is Complete.					Time lost repairing hydraulic fitting.	Total Time.				
		Straight.	Bore No. 1.	Bore No. 2.	Taper.	Mean.	Straight.	Bore No. 1.	Bore No. 2.	Taper.	Mean.		Straight.	Bore No. 1.	Bore No. 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
4-32	Time for jacks for light iron is included in shoving and mucking.	6-23	....	....	....	6-23	Excavation partially completed previously.					....	10-55			.....	10-55
39-33		4-25	....	....	5-10	4-29						....	43-58	......	......	44-43	44-02
15-05		2-53	....	....	3-15	2-55						0-04	18-02	......	......	18-24	18-04
6-56		2-27	....	....	2-21	2-26						0-09	9-32	......	.	9-26	9-31
6-19		2-31	J	J	6-30	2-37						0-07	8-57	......	......	12-56	9-03
6-13		1-57	2-44	2-52	2-00	2-15						0-15	8-25	9-12	9-20	8-28	8-43
1-45		1-58	1-57	2-15	2-45	2-02						0-14	3-57	3-56	4-14	4-44	4-01
1-08		0-58	1-45	1-50	....	1-17						....	2-06	2-53	2-58	.....	2-35
4-03		2-20	1-40	1-55	2-57	2-22	Bolting time for light iron is included in erection.					....	6-23	5-43	5-58	7-00	6-25
0-36		2-00	1-34	2-42	1-53	2-02						....	2-36	2-10	3-18	2-29	2-38
1-11		2-15	2-20	....	2-43	2-33						0-39	4-05	4-10	......	4-43	4-23
0-33		2-03	2-04	2-09	2-23	2-06						0-14	2-50	2-51	2-56	3-10	2-53
1-23		2-49	2-30	2-50	1-50	2-38						0-27	4-39	4-20	4-40	3-40	4-28
1-28		2-35	2-23	1-55	2-10	2-26						....	4-03	3-51	3-23	3-38	3-54
1-44		2-12	2-34	2-29	2-15	2-19						....	3-56	4-18	4-13	3-59	4-03
1-07		1-54	2-33	2-16	1-35	2-04						....	3-01	3-40	3-23	2-42	3-11
1-13	......	2-14	2-55	2-35	2-46	2-28						....	3-27	4-08	3-48	3-59	3-41
......	......	....	....	....	....	....						....	......	......	......	.....	.....
1-58	*	2-07	2-19	2-26	2-15	2-[illegible]3						0-09	4-14	4-26	4-33	4-22	4-20
1-08	*	1-20	2-08	1-65	1-40	1-41	0-40	0-35	1-25	0-55	0-47	....	3-08	3-51	4-28	3-43	3-36
0-36	0-12	1-21	1-22	1-26	1-55	1-23	0-31	0-29	0-38	0-30	0-32	0-12	2-52	2-51	3-04	3-25	2-55
0-29	0-14	0-46	1-25	1-31	2-37	1-10	0-48	0-31	0-44	0-35	0-43	0-05	2-22	2-44	3-03	4-00	2-41
0-40	0-11	0-48	1-31	1-34	0-53	1-03	0-31	1-03	0-49	3-27	0-51	....	2-10	3-25	3-14	5-11	2-45
0-48	0-19	0-54	1-12	1-02	1-23	1-01	0-22	0-37	0-38	0-20	0-27	0-06	2-29	3-02	2-53	2-56	2-41
0-33	0-16	0-59	0-45	1-15	1-20	1-01	0-22	0-21	0-45	0-40	0-26	0-45	2-55	2-40	3-34	3-34	3-01
0-20	0-14	0-49	1-02	1-01	0-50	0-54	0-41	0-36	0-36	0-15	0-39	0-12	2-16	2-24	2-23	1-51	2-19
0-34	0-14	0-40	0-40	0-48	....	0-44	1-15	0-15	0-28	....	0-48	....	2-43	1-43	2-04	.....	2-20
0-21	0-11	0-40	0-48	0-39	....	0-41	0-41	0-34	0-55	....	0-41	....	1-53	1-54	2-06	.....	1-54
0-18	0-10	0-43	0-44	0-46	0-40	0-43	0-35	1-15	1-07	0-35	0-48	0-04	1-50	2-31	2-25	1-47	2-03
0-33	0-12	0-50	1-02	1-06	0-58	0-55	0-35	0-46	0-58	2-10	0-41	0-21	2-31	2-54	3-10	4-14	2-42
0-30	0-14	0-56	1-08	1-12	1-29	1-02	0-36	0-36	0-44	0-54	6-38	0-11	2-27	2-39	2-51	3-18	2-35
1-29	0*	1-48	2-01	2-11	2-17	1-56	‡	...	....	....	......	0-10	3-18	3-31	3-41	3-47	3-26
3-13	*	....	....	....	....	2-05	†	....	....	....	......	0-09	......	......	......	.....	5-27

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring.			
		Shoving and mucking. *	Erection †	Lost time.	Total.
46	0-06	4-32	6-23	0	10-55
46	0-51	39-33	4-29	0	44-02
44	0-21	15-05	2-55	0-04	18-04
39	0-11	6-56	2-26	0-09	9-31
42	0-09	6-19	2-37	0-07	9-03
43	0-09	6-13	2-15	0-15	8-43
11	0-07	1-13	2-20	0-08	3-41
24	0-14	5-06	2-24	0-08	7-38
8	0-04	0-44	1-40	0-11	2-35
17.1	0-12	3-13	2-05	0-09	5-27

Unavoidable Delays (not Included in Average Time per Ring).		
Items.	Time. hrs.	min.
First bulkhead............	132	00
Second bulkhead..........	158	50
Grouting..................	240	00
Old cave-in................	234	00
Shoving tube..............	128	00
Total..................	892	50
Per ring..............	0	49

‡ Excavating ahead of shield. § Shoving shield into silt with.....doors open.

TABLE 27.—SHIELD-DRIVEN TUNNEL WORK,

Table showing the size of the gang, the amount of excavation, and the through the several kinds of ground encountered; also

Weight of iron.	Section between rings.	Description.				Ave. No. of Men in Gang.					Ave. No. of cu. yd. per ring.	Time mucking, per cu. yd.
		Length, in feet.	Material.	Ave. air pressure	Method of excavation.	Shield. A	Drilling. B	Grout'g. C	Air trans. D	Total.	E	
Ordinary.	1–27	67.5	Rock	9	‡	Excavation partially completed previously.						
	28–42	37.5	"	12	‡	13	4	1	1	19	48.7	0–25
	43–58	40.0	Rock or gravel	12	‡	19	2	2	2	25	44.2	0–46
	59–153	237.5	Gravel and sand	16	‡ Breast'g.	25	...	1	4	30	39.0	0–12
	154–170	42.5	Sand and silt with piles.	18	"	26	...	1	5	32	41.6	0–10
	171–236	165.0	Silt with piles	22	Top half...	22	...	1	3	26	42.6	0–10
	237–259	57.5	Silt	25	§ 1 door...	18	...	1	3	22	13.8	0–11
	260–302	107.5	"	27	§ 1 " ...	15	...	...	2	17	0	....
	303–350	120.0	"	27	§ 8 doors..	15	...	...	4	19	6.9	0–07
	351–378	70.0	"	27½	§ 8 " ..	18	...	...	6	24	0	....
	379–424	115.0	"	27½	§ 8 " ..	19	...	...	4	23	6.9	0–07
	425–522	245.0	"	28	§ 1 door...	19	...	...	4	23	6.7	0–06
	523–625	257.5	"	28	§ 1 " ...	20	...	...	4	24	0	....
	171–625	1 137.5	....	27	....	19	...	...	4	23	9.7	0–11
	28–625	1 495.0	....	25	....	19	0.8	0.8	3.4	24	17.8	0–14
Heavy.	626–649	57.5	Silt	28	§ 1 door...	16	...	...	3	19	12.2	0–12
	650–733	210.0	"	28	§ 8 doors..	19	...	...	4	23	13.5	0–04
	734–753	50.0	"	28	§ 8 " ..	24	...	...	5	29	8.3	0–05
	754–844	227.5	"	28	§ 8 " ..	26	...	...	8	34	12.8	0–04
	845–859	37.5	"	28	§ 8 " ..	27	...	...	9	36	5.6	0–07
	860–899	100.0	"	28	§ 8 " ..	24	...	...	8	32	16.5	0–02
	900–935	90.0	"	28	§ 1 door...	25	...	...	7	32	11.5	0–03
	936–963	70.0	"	28	§ 1 " ...	25	...	...	8	33	5.9	0–03
	964–1 003	100.0	"	28	§ 1 " ...	25	...	...	10	35	8.1	0–03
	1 004–1 060	142.5	"	28	§ 1 " ...	26	...	...	10	36	8.7	0–03
	1 061–1 110	125.0	"	28	§ 1 " ...	37	...	...	10	47	6.2	0–03
	1 111–1 238	320.0	"	28	§ 1 " ...	30	...	...	9	39	15.6	0–02
	1 239–1 312	185.0	"	28	....	39	...	...	9	38	13.0	0–03
	626–1 312	1 717.5	"	28	....	25	...	...	8	33	10.6	0–04
All.	171–1 312	2 855.0	....	28	....	23	...	...	6	29	10.2	0–07
	28–1 312	3 212.5	....	26	....	21	...	...	5	26	14.1	0–10

SUM

Weight of iron.	Section between rings.	Description.				Aver. No. of Men in Gang.				
		Length, in feet.	Material.	Ave. air.	Method of excavation.	Shield.	Drilling.	Grouting.	Air transport.	Total.
Ordinary.	28–42	37.5	Rock	12	‡Breast....	13	4	1	1	19
	43–58	40.0	Rock and gravel	12	"	19	2	2	2	25
	59–153	237.5	Gravel and sand	16	"	25	....	1	4	30
	154–170	42.5	Sand or silt, with piles...	18	"	26	....	1	5	32
	171–236	165.0	Silt, with piles	22	"	22	....	1	3	26
	237–259	57.5	Silt	25	§1 door....	18	....	1	3	22
	260–625	915.0	"	27	1 "	18	....	....	4	22
	28–625	1 495.0	....	25	....	19	0.8	0.8	3.4	24
Heavy.	626–1 312	1 717.5	Silt	28	....	25	....	....	8	33
All.....	28–1 312	3 212.5	....	26	....	21	....	....	5	26

* Including time for jacks. † Including bolting time.

WEEHAWKEN SHAFT, RIVER TUNNEL SOUTH.

time per ring taken for the various operations involved in building tunnel the extent and nature of all the unavoidable delays.

Ave. time per ring, shoving and mucking.	Time for jack.	Time for Ring Erection, Hrs. and Min.					Bolting Time (Whole Time on Bolts after Ring is Complete).					Time lost repairing hydraulic fittings.	Total Time.				
		Straight.	Bore 1.	Bore 2.	Taper.	Mean.	Straight.	Bore 1.	Bore 2.	Taper.	Mean.		Straight.	Bore 1.	Bore 2.	Taper.	Mean.
	F	G	G	G	G	G	H	H	H	H	H						
......	....	8-30	....	....	3-45	8-08						0-14	21-11	......	......	16-26	20-49
20-33	....	4-23	....	....	4-00	4-21						0-12	25-08	......	......	24-45	25-06
33-44	....	4-16	....	....	5-45	4-44						1-15	39-15	......	......	40-44	39-43
8-06	....	2-19	....	....	4-18	2-23						0-30	10-55	......	......	12-54	10-59
7-10	....	2-00	J.	J.	1-48	1-59						0-0	9-10	J.	J.	8-58	9-09
7-23	....	2-36	2-55	2-58	1-24	2-35	Bolting time for light iron is included in erection.					0-05	10-04	10-23	10-26	8-52	10-03
2-29	....	3-01	2-05	1-28	2-00	2-32						0-20	5-50	4-54	4-17	4-49	5-21
0-32	....	2-34	2-35	3-38	4-28	3-05						0-08	3-14	3-15	4-18	5-08	3-45
0-52	....	2-59	2-28	2-37	1-44	2-41						0-07	3-58	3-27	3-36	2-43	3-40
0-33	....	2-05	2-32	2-48	2-00	2-18						0-17	2-55	3-22	3-38	2-50	3-08
0-48	....	3-34	2-51	3-18	3-19	3-22						0-25	4-47	4-09	4-31	4-32	4-35
0-45	....	3-09	3-51	3-00	3-28	3-16						0-16	4-10	4-52	4-01	4-29	4-17
0-32	....	1-36	1-37	1-47	1-51	1-39						0-12	2-20	2-21	2-31	2-35	2-23
1-44	*	2-37	2-41	2-41	2-32	2-38						0-13	4-34	4-38	4-38	4-29	4-35
4-14	*	....	....	....	....	2-41						0-16	......	......	......	......	7-11
2-23	*	2-19	2-30	2-05	1-42	2-16	1-01	1-04	1-04	0-50	1-01	0-32	6-15	6-29	6-04	5-27	6-12
0-57	0-13	1-42	1-24	1-47	1-48	1-39	1-15	0-52	0-55	0-42	1-07	0-32	4-39	3-58	4-24	4-12	4-28
0-41	0-17	1-06	1-55	0-38	1-20	1-12	0-38	0-44	1-13	0-20	0-44	0-06	2-48	3-43	2-55	2-44	3-00
0-51	0-16	1-19	1-41	1-52	0-50	1-29	0-39	0-50	0-54	0-40	0-44	0-25	3-30	4-03	4-18	3-02	3-45
0-39	0-19	1-24	1-08	1-10	....	1-20	0-45	0-15	0-15	....	0-37	0-48	3-55	3-09	3-11	......	3-43
0-39	0-13	1-00	1-05	1-13	....	1-04	0-59	0-32	0-49	....	0-52	0-07	2-58	2-36	3-01	......	2-55
0-29	0-14	0-47	1-13	0-52	1-10	0-52	0-39	0-43	0-32	0-20	0-38	0-04	2-13	2-43	2-11	2-17	2-17
0-19	0-15	0-59	0-47	0-55	....	0-56	0-34	0-16	0-41	....	0-32	0-37	2-44	2-14	2-47	......	2-39
0-27	0-10	0-51	0-52	1-05	....	0-53	0-32	0-45	0-37	....	0-35	0-16	2-16	2-30	2-35	......	2-21
0-30	0-15	1-01	1-09	1-05	0-45	1-03	0-54	0-37	0-49	0-40	0-49	0-24	3-04	2-55	3-03	2-34	3-01
0-19	0-10	0-42	0-49	0-54	0-45	0-45	0-24	0-26	0-39	0-25	0-27	0-0	1-35	1-44	2-02	1-39	1-41
0-38	0-16	0-48	1-06	1-04	1-23	0-56	0-36	0-34	0-57	1-12	0-41	0-02	2-20	2-36	2-57	3-31	2-33
0-36	0-18	1-04	1-01	1-02	1-15	1-07	0-39	0-43	1-12	0-59	0-50	0-10	2-47	2-48	3-18	3-18	3-01
0-42	0-14	1-06	1-15	1-16	1-18	1-10	0-45	0-40	0-52	0-54	0-47	0-16	3-03	3-07	3-20	3-24	3-09
1-15	*	2-09	2-13	2-21	2-20	2-13	†	....	....	....	....	0-15	3-39	3-43	3-51	3-50	3-43
2-28	*	....	....	....	....	2-18	†	....	....	....	....	0-15	......	......	......	......	5-01

MARY.

Average No. of cubic yards per ring.	Time mucking, per cubic yard.	Average Time per Ring.				Unavoidable Delays (Not Included in Average Time per Ring.)		
		Shoving and mucking. *	Erection. †	Lost time.	Total.	Items.	Time, hrs.	min.
48.7	0-25	20-33	4-21	0-12	25-06	1st bulkhead................	80	00
44.2	0-46	33-44	4-44	1-15	39-43	2d "	156	00
39.0	0-12	8-06	2-23	0-30	10-59	Grouting rock section......	280	00
41.6	0-10	7-10	1-59	0-0	9-09	Blow-outs..................	222	00
42.6	0-10	7-23	2-35	0-05	10-03	Shield repairs	326	40
13.8	0-11	2-29	2-32	0-20	5-21	Horizontal timbers..........	69	30
3.6	0-06	0-40	2-39	0-14	3-33	Total.................	1 134	10
17.8	0-14	4-14	2-41	0-16	7-11	Per ring............ ..	0	53
10.6	0-4	0-56	1-57	0-16	3-09	....	....	
14.1	0-10	2-28	2-18	0-15	5-01	....	....	

‡ Excavating ahead of shield. § Shoving shield into silt with......doors open.

taining No. 1 bore segments, rings centaining No. 2 bore segments, and taper rings, and it will be seen that, on the average, taper rings took 22 min. (or 24%) more time to erect and to bolt than ordinary ones, and that rings containing No. 2 bore segments took 14 min. (or 15%) more.

The average time taken for each operation at all the working faces is given in Table 28. The work has been subdivided into the different kinds of ground encountered.

The progress, as shown by the amount of work done each month by each shield, is given in Table 29.

TABLE 28.—SHIELD-DRIVEN TUNNEL WORK.—TOTAL NUMBER OF TRACTS GY-WEST AND GJ, AND THE AVERAGE SIZE OF GANG, VARIOUS OPERATIONS INVOLVED IN BUILDING TUNNEL IN ALSO THE EXTENT AND NATURE OF

Weight of iron.	Description of materials.	Total No. of rings.	Total No. of feet.	Total number of 8-hour shifts.	Average air pressure.	Ave. No. of Men in Gang.				
						Shield.	Drilling.	Grout-ing.	Air Transp't.	Total.
						Unit.	Unit.	Unit.	Unit.	Unit.
Ordinary iron.	Rock	165	412.5	597	16	18	9	0.25	1	28
	Rock and earth and rock and gravel	177	442.5	500	14	22	5	0.3	2	30
	Sand and gravel (unobstructed), N. J.	188	470.0	241	13	24	......	0.6	3	27
	Sand and silt (with piles)	171	427.5	199	22	23	......	1.0	3	27
	Silt under R. R. tracks, N.Y.	396	990.0	355	19	27	......	......	3	30
	Rip-rap and silt under bulkhead	77	192.5	193	23	26	......	......	4	30
	Total mixed and difficult ground	1 174	2 935.0	2 085	17	22	4	0.3	3	29
	Silt—ordinary iron	1 302	3 255.0	676	25	22	......	......	4	26
Heavy.	Silt—heavy iron	2 209	5 522.5	791	26	25	......	......	8	33
	Silt—ord. and heavy iron under river	3 511	8 777.5	1 467	26	24	......	......	6	30
	Grand total	4 685	11 712.5	3 552	21	23	2	0.2	4	29

Average rings built by one shield = 1 146¼.

Average time per ring..

Delays..

Total time per ring..

NOTE.—The "unavoidable delays" included in this table do not embrace the periods observations. shortage of iron due to change of design, and holidays.

K. Including time for jacks.

L. Including time spent by the whole gang on bolting; in addition to this there was

M. Chiefly due to breakdowns of hydraulic lines and erector.

Air Pressure.—The air pressure varied from 17 to 37 lb. Behind the river line it averaged 17 lb. and under the river 26 lb. Behind the river lines the pressure was generally kept about equal to the water head at the crown, except where at Weehawken, as previously described, this was impossible.

In the silt the pressure was much lower than the hydrostatic head at the crown, but if it became necessary to make an excavation ahead of the shield, for example at the junction of the shields, the air pressure required was about equal to the weight of the overlying material, namely, the water and the silt, as the silt, which weighed from

RINGS ERECTED AND SHIFTS WORKED BY ALL FOUR SHIELDS IN CON-
AMOUNT OF EXCAVATION AND TIME TAKEN PER RING FOR THE
EACH OF THE SEVERAL KINDS OF GROUND ENCOUNTERED;
ALL THE UNAVOIDABLE DELAYS.

Cu. yd. per ring.	Time per cu. yd	Average Time per Ring.								Ave. Unavoidable Delay per Working Face.		
		Shoving and mucking.		Erecting.		Lost time.		Total.		Items not included in previous figures.	Time.	
											Ave. unit.	
		Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.		Hrs.	Min.
Unit.	Unit.	K		L		M						
51	0-27	25	15	3	41	0	02	28	58	1st Bulkhead......	136	00
45	0-26	19	31	2	55	0	11	22	37	2d "	147	54
39	0-12	7	31	2	24	0	20	10	15	Grouting.....	246	00
43	0-09	6	46	2	24	0	09	9	19	Blow-outs..........	91	11
42	0-06	4	09	2	51	0	10	7	10	Miscellaneous.....	230	33
43	0-21	14	47	3	41	1	34	20	02	Total..............	851	38
43	0-18	11	02	2	54	0	16	14	12	....	....	
12	0-07	1	20	2	35	0	14	4	09	....	....	
12	0-05	0	58	1	44	0	10	2	52	....	....	
12	0-06	1	09	2	05	0	12	3	26	....	....	
20	0-11	3	33	2	15	0	13	6	01	....	....	

Average delay per ring = 0 hrs. 44 min.

.... 6 hrs. 01 min.
.... 44 min.

.... 6 hrs. 45 min.

during which the work was at complete or partial standstill due to experiments and

a small gang which spent its whole time bolting.

TABLE 29.—MONTHLY PROGRESS OF SHIELD-DRIVEN TUNNEL WORK.

Month.		North Manhattan.				South Manhattan.				North Weehawken.				South Weehawken.				Average progress per shield, lin. ft. per month.
		Number of rings erected.		Station of leading ring.	Lin. ft. for month.	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	Number of rings erected.		Station of leading ring.	Lin. ft. for month.	
		For month.	To date.			For month.	To date.			For month.	To date.			For month.	To date.			
1905.	May	26	26	200 + 83.7	63.7	......	......	......	......	......	......	......	......	......	......	......	......	15.9
	June	26	52	201 + 49.0	65.3	......	......	......	......	24	24	260 + 76.6	59.3	12	12	260 + 70.0	30.0	38.6
	July	28	80	202 + 19.2	70.2	......	......	......	......	12	36	260 + 46.6	30.0	15	27	260 + 32.4	37.6	34.4
	Aug.	26	106	202 + 84.3	65.1	......	......	......	......	15	51	260 + 09.1	37.5	16	43	260 + 07.4	25.0	31.9
	Sept.	21	127	203 + 36.8	52.5	31	31	200 + 96.4	76.4	1	52	260 + 06.6	2.5	18	61	259 + 47.2	60.2	47.9
	Oct.	25	152	203 + 99.4	63.6	45	76	202 + 09.2	112.8	10	62	259 + 81.5	25.1	20	81	258 + 97.2	50.0	62.9
	Nov.	31	183	204 + 76.9	77.5	31	107	202 + 86.5	77.3	29	91	259 + 09.0	72.5	39	120	257 + 99.7	97.5	81.2
	Dec.	59	242	206 + 24.6	147.7	34	141	203 + 71.8	85.3	46	137	257 + 94.0	115.0	77	197	256 + 07.1	192.6	135.1
1906.	Jan.	94	336	208 + 59.8	235.2	27	168	204 + 39.4	67.6	77	214	256 + 01.4	192.6	73	270	254 + 24.6	182.5	169.4
	Feb.	78	414	210 + 54.9	195.1	64	232	205 + 99.6	160.2	133	347	252 + 68.6	332.8	165	435	250 + 11.7	412.9	275.2
	Mar.	56	470	211 + 95.2	140.3	96	328	208 + 39.9	240.3	142	489	249 + 13.3	355.3	111	546	247 + 34.0	277.7	253.4
	April	119	589	214 + 93.0	297.8	84	412	210 + 50.1	210.2	32	521	248 + 33.3	80.0	78	624	245 + 38.9	195.1	195.7
	May	129	718	218 + 15.7	322.7	70	482	212 + 25.3	165.2	121	642	245 + 30.6	302.7	2	626	245 + 33.9	5.0	198.9
	June	218	936	223 + 60.9	545.2	140	622	215 + 75.5	350.2	162	804	241 + 25.3	405.3	157	783	241 + 41.1	392.8	423.4
	July	155	1 091	227 + 48.5	387.6	82	704	217 + 80.7	205.2	113	917	238 + 42.4	282.9	118	901	238 + 45.9	295.2	292.7
	Aug.	145	1 236	231 + 11.2	362.7	134	838	221 + 15.8	335.1	138	1 055	234 + 97.1	345.3	140	1 041	234 + 95.8	350.1	348.3
	Sept.	89	1 325	233 + 34.1	222.9	168	1 006	225 + 35.8	420.0	55	1 110	233 + 59.5	137.6	177	1 218	230 + 52.8	443.0	305.9
	Oct.	......	......	......	......	105	1 111	227 + 98.6	262.8	1	1 111	233 + 57.0	2.5	94	1 312	228 + 16.8	236.0	125.3
	Nov.	......	......	......	......	7	1 118	228 + 16.8	18.2	9	1 120	233 + 34.1	22.9	......	......	......	......	10.3

97 to 106 lb. per cu. ft. and averaged 100 lb. per cu. ft., acted like a fluid.

A ½-in. air line was taken direct from the working chamber to the recording gauges in the engine-room, which enabled the engine-room force to keep a constant watch on the air conditions below. To avoid undue rise of pressure, a safety valve was set on the air line at each lock, set to blow off if the air pressure rose above that desired. The compressor plant was ample, except, as before described, when passing the gravel section at Weehawken.

Records were kept of the air supply, and it may be said here that the quantity of free air per man per hour was in general between 1 500 and 5 000 cu. ft., though in the open gravel where the escape was great it was for a time as much as 10 000 cu. ft. For more than half the silt period it was kept between 3 000 and 4 000 cu. ft., but when it seemed proved beyond doubt that any quantity more than 2 000 cu. ft. had no beneficial effect on health, no attempt was made to deliver more, and on two separate occasions for two consecutive weeks it ran as low as 1 000 cu. ft. without any increase in the number of cases of bends.

The amount of CO_2 in the air was also measured daily, as the specifications called for not more than 1 part of CO_2 per 1 000 parts of air The average ranged between 0.8 and 1.5 parts per 1 000, though in exceptional cases it fell as low as 0.3 and rose to 4.0. The air temperature in the tunnels usually ranged from 55° to 60° Fahr., which was the temperature also of the surrounding silt, though at times, in the earlier parts of the work when grouting extensively in long sections of the tunnel in rock, it varied from 85° to 110° Fahr.

Grouting.—Grout of one part of Portland cement to one part of sand by volume was forced outside the tunnel lining by air pressure through 1½-in. tapped and plugged grout holes formed in each segment for this purpose, wherever the ground was not likely to squeeze in upon the metal lining as soon as this was erected. That is to say, it was used everywhere up to the river line; between river lines it was not used except at the New York bulkhead wall in order to fill voids in the rip-rap, and at the point of junction of the shields where the space between the metal lining and the shield skins outside it was grouted. Cow Bay sand was used, and it had to be screened to remove particles greater than $\frac{1}{16}$ in. in diameter, which would choke the valves.

For later grouting work, namely, in the top of the concrete lining inside the metal lining, Rockaway Beach sand was used. This is very fine, and did not need screening; it cost more, but the saving of screening and the non-blocking of valves, etc., resulted in a saving.

The grout was mixed in a machine shown in Fig. 2, Plate XCV, which is a view of the grouting operation.

The grout pipes were not screwed directly into the tapped hole in the segments, but a pipe containing a nipple and valve was screwed into the grout hole and the grout pipe screwed to the pipe. This prevented the waste of grout, enabled the valve to be closed and the grout pipe disconnected, and the pipe to be left in position until the grout had set. In the full rock section, 20 or 30 rings were put in without grouting; then the shield was stopped, the last two or three rings were detached and pulled ahead by the shield, a masonry stop-wall was built around the outside of the last ring left in, and the whole 20 or 30 rings were grouted at one time. In the landward silt and gravel each ring had to be grouted as soon as the shield had left it, in order to avoid the flattening caused by the weight coming on the crown while the sides were as yet unsupported. The grout was prevented from reaching the tail of the shield by plugging up the space with empty cement bags, assisted by segmental boards held against the face of the leading ring by U-shaped clamps, fitting over the front circumferential flange of the ring and the boards, and tightened by wedges. The air pressure varied between 70 and 100 lb. per sq. in. above normal.

The force consisted of one pipe fitter and one or two laborers employed part of their time. When a considerable length was being grouted at a time, as in the full rock section, many laborers were employed for a short period.

Transportation and Disposal.

The transportation and disposal will be described under the following headings:

Receipt and Unloading of Materials,
Surface Transportation,
Tunnel Transportation,
Disposal.

Receipt and Unloading of Materials.—At the Manhattan Shaft the contractor laid a spur siding into the yard from the freight tracks of the New York Central Railroad, which immediately adjoins the yard on the west. There was also wharfage on the river front about 1 500 ft. away.

At the Weehawken Shaft there were four sidings from the Erie Railroad and one from the West Shore Railroad. Access to the river was gained by a trestle direct from the yard, and Baldwin Avenue adjoined the yard.

All the iron lining arrived by railroad. It was unloaded by derricks, and stacked so that it was convenient for use in the tunnel. The Manhattan derricks were a pair of steel ones with 39-ft. booms, worked by a 30-h.p., 250-volt, electric motor. There was also a stiff-leg derrick with 50-ft. boom, on a platform near the shaft, which was worked by a 40-h.p., 250-volt motor. At Weehawken there were two 45-ft. boom, stiff-leg derricks of 2 tons capacity, one worked by a 42-h.p. Lidgerwood boiler and engine, and the other by a 25-h.p., 250-volt, electric motor. These derricks were set on elevated trestles near the Erie Railroad sidings. There was a 50-ft. stiff-leg derrick with a 70-h.p. Lidgerwood boiler and engine near the cement warehouse on the West Shore Railroad.

The storage area for iron lining was 1 800 sq. ft. at Manhattan and 65 000 sq. ft. at Weehawken; the maximum quantity of lining in storage at any one time was 150 rings at Manhattan and 1 200 rings at Weehawken.

The cement, which was issued and sold by the Company to the contractor, was kept in cement warehouses; that at the New York side was at Eleventh Avenue and 38th Street, or some 1 200 ft. from the shaft, to which it was brought by team; that at Weehawken was adjacent to the shaft, with a 2-ft. gauge track throughout it and directly connected with the shaft elevator.

Surface Transportation.—In the early days the excavation was handled in scale-boxes of 1 cu. yd. capacity which were hoisted up the shafts by a derrick, but, when the iron period began, two-cage elevators were put in at each shaft. They were worked by a single, friction-drum, Lidgerwood, steam hoisting engine of 40 h.p.

All materials of construction were loaded on cars on the surface at the point where they were stored, and hauled on these to the ele-

vators, sent down the shaft, and taken along the tunnels to the desired point without unloading.

The narrow-gauge railway on the surface and in the tunnel was of 2-ft. gauge with 20-lb. rails. About 70 flat cars and 50 mining cars were used at each shaft. On the surface at Manhattan these were moved by hand, but at Weehawken, where distances were greater, two electric locomotives on the overhead trolley system were used.

Tunnel Transportation.—The mining cars shown in Fig. 19 were of 1¼ cu. yd. capacity. The short wheel base and unbalanced loading caused a good many upsets, but they were compact, easily handled, and could be dumped from either side or end.

MUCK CAR (AS USED IN RIVER TUNNELS)
CAPACITY 5000 LBS. OR 1 CU. YD.

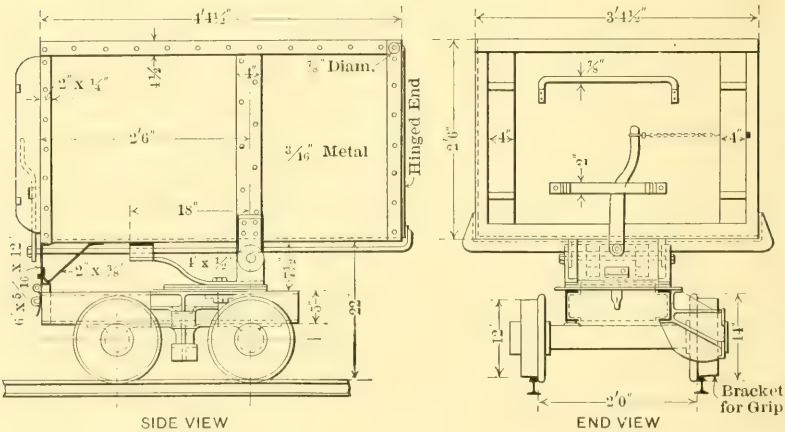


FIG. 19.

The flat cars shown in Fig. 20 were of 3 tons capacity, and could hold two tunnel segments. As the working face was down grade from the shafts, the in-bound cars were run by gravity. For out-bound cars a cable haulage system was used, consisting of double-cylinder, Lidgerwood, single friction-drum, hoisting engines (No. 32) of 6 h.p., with cylinders 5 in. in diameter and 6 in. stroke and drums 10 in. in diameter. These were handily moved from point to point, but, as there was no tail rope, several men had to be used to pull the cable back to the face. After the second air-lock bulkhead walls had been built, a continuous-cable system, worked electrically, was put in each tunnel between the first and second air-locks.

The engine consisted of an electric motor driving a 3-ft. 6-in. drum hoist around which a ¾-in. steel wire cable passed three times. The cable was led around a sheave, down the tunnel on the right side of the in-bound track, and returned on the left side of the out-bound track. It was then carried around a set of sheaves, where a tension

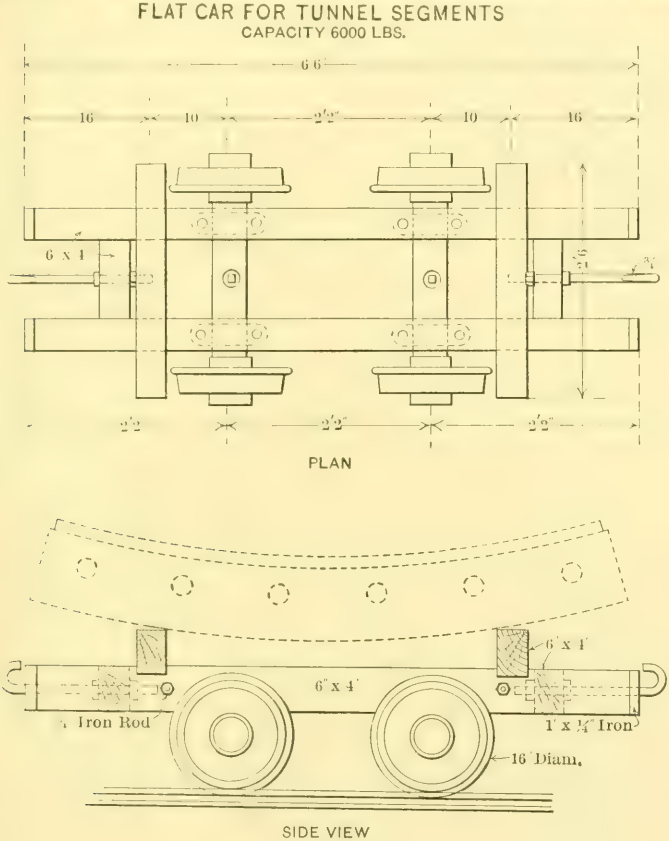


FIG. 20.

of 1 000 lb. was supplied by a suspended weight which acted on a sheave with a sliding axle on the tension carriage. The cable was supported throughout its length on 8-in. pulleys set in the floor at 50-ft. intervals. All the guide sheaves were 36 in. in diameter.

Each car was attached to the cable by a grip at its side. This was fastened and unfastened by hand, but was automatically released just before reaching the turn in the cable near each lock. This

system could haul without difficulty an unbalanced load of 10 muck cars, spaced 100 ft. apart, up a 2% grade. The cable operated over about 1 000 ft. of tunnel, the motor being placed at the top of the grade. The driving motor was of the semi-armored, 8-pole, series-wound type, rated at 25 h.p., 635 rev. per min., and using direct current at 220 volts. The speed of handling the cars was limited by their having to pass through the air-locks on a single track. As many as 106 cars have been hauled each way in one 8-hour shift.

Disposal.—At Manhattan the tunnel muck was carried from the elevator over the upper level of the yard trestle and dumped into bins on the 33d Street side, whence it was teamed to the public dump at 30th Street and North River. At Weehawken the rock excavation was removed by the Erie Railroad on flat cars on which it was dumped by the tunnel contractor, but all the silt muck was teamed away to some marshy ground where dumping privileges were obtained.

The typical forces employed on transportation were as follows:

Receipt and Unloading of Material: Surface Transportation and Disposal.

At Manhattan Shaft, on 10-hour shifts:

2	Engineers on derricks	@	$3.00	per day.
2	Foremen	"	3.25	" "
15	Laborers loading and unloading iron.	"	1.75	" "
7	Laborers on disposal	"	1.75	" "
6	Teams	"	7.50	" "

At Weehawken Shaft, on 10-hour shifts:

3	Engineers on derricks and locomotives	@	$3.00	per day.
16	Laborers loading and unloading iron.	"	1.75	" "
3	Foremen	"	3.50	" "
11	Laborers on disposal	"	1.75	" "
6	Teams on disposal	"	6.50	" "

Tunnel Transportation (Including Shaft Elevator):

Shaft elevators and to and from the first air-lock on 10-hour shift:

2	Engineers	@	$3.00	per day.
2	Signalmen	"	2.00	" "
1	Foreman	"	3.00	" "
12	Laborers	"	1.75	" "

Between first lock and working face, on 8-hour shifts, the force varied:

From 1 to 3 (average 2) Hoist engineers	@ $3.00	per	day.
From 0 to 2 (average 1) Lockman	" 2.75	"	"
From 1 to 2 (average 2) Trackmen...	" 3.00	"	"
From 2 to 7 (average 4) cablemen (pulling back cable)..............	" 3.00	"	"

Pumping.—The water was taken out of the invert by a 4-in. blow-pipe which was always kept up to a point near the shield and discharged into the sump near the shaft.

When the air pressure was removed and the blow-pipe device, consequently, was unavailable, small Cameron pumps, driven by compressed air, and having a capacity of about 140 gal. per hour, were used, one being set up wherever it was necessary to keep the invert dry; for example, at points where caulking was in progress.

Lighting.—The tunnels were lighted by electricity, the current being supplied, at a pressure of 250 volts, from the dynamos in the contractor's power-house.

Two 0000 wire cables were used as far as the second air-locks, about 1 650 ft. from the power-house, on each side; and beyond that point, to the junction of the shields (about 1 750 ft.), 00 and 0 wires were used. These cables also carried the current for the cable haulage system. Two rows of 16-c.p. lamps, provided with reflectors, were used in each tunnel; one row was along the side just above the axis, with the lights at about 30-ft. intervals; the other along the crown, with the lamps halfway between the side lamps, also at 30-ft. intervals. At points where work was in progress three groups of 5 lights each were used. The tunnels as a whole were well lighted, and in consequence work of all kinds was much helped.

Period No. 2.—Caulking and Grummeting.—November, 1906, to June, 1907.—After the metal lining had been built completely across the river in both tunnels, the work of making it water-tight was taken up. This consisted in caulking into the joints between the plates a mixture of sal-ammoniac and iron borings which set up into a hard rusty mass, and in taking out each bolt and placing around the shank under the washer at each end a grummet made of yarn

soaked in red lead. These grummets were made by the contractor on the works, and consisted of three or four strands of twisted hemp yarn, known as "lath yarn," making up a rope-like cross-section about ¼ in. in diameter. Usually, one of these under each washer was enough, but in wet gravel, or where bolts were obliquely in the bolt-holes, two were used at each end. After pulling the grummets in, all the nuts were pulled up tight by wrenches about 3 ft. long, with two men on one wrench. Bolts were not passed as tight unless the nut resisted the weight of an average man on a 2½-ft. wrench.

Before putting in the caulking mixture, the joints were carefully scraped out with a special tool, cleaned with cotton waste, and washed with a stream of water. The usual mixture for sides and invert was about 2 lb. of sal-ammoniac and 1 lb. of sulphur to 250 lb. of iron filings or borings. In the arch, 4 lb. of sal-ammoniac and 3 lb. of sulphur to 125 lb. of filings was the mixture. A small hand-hammer was used to drive the caulking tool, but, in the sides and invert, air hammers were used with some advantage. The success of work of this kind depends entirely on the thoroughness with which the mixture is hammered in; and the inspection, which was of an exceedingly monotonous nature, called for the greatest care and watchfulness on the part of the Company's forces, especially in the pocket iron, where each bolt had to be removed, the caulking done at the bottom of the pockets put in, the bolts replaced, and the rest of the pockets filled. The results have been satisfactory, as the leakage under normal air and prior to placing the concrete averaged about 0.14 gal. per lin. ft. of tunnel per 24 hours, which is about 0.0035 gal. per lin. ft. of joint per 24 hours. With each linear foot of joint is included the leakage from 1.27 bolts. Afterward, when the concrete lining was in, the leakage was found to be about 0.05 to 0.06 gal. per lin. ft. of tunnel per 24 hours, which compares favorably with the records of other lined tunnels. The typical gang employed on this work was as follows:

In Pocket Iron:

1 General foreman	@	$5.00	per	day.
1 Mixer	"	3.00	"	"
1 Nipper	"	3.00	"	"
5 Caulkers	"	3.00	"	"
10 Grummeters	"	3.00	"	"

In Pocketless Iron:

1 General foreman	@	$5.00	per day.
1 Mixer	"	3.00	" "
1 Nipper	"	3.00	" "
3 Caulkers	"	3.00	" "
12 Grummeters	"	3.00	" "

The average amount of caulking and grummeting done per shift with such a gang was (with pocketless grooves), 348 lin. ft. of joint and 445 bolts grummeted; and in pocket iron: 126 lin. ft. of joint and 160 bolts grummeted.

The caulking and grummeting work was finished in June, 1907, this completing the second period.

Period No. 3.—Experiments, Tests, and Observations.—April, 1907, to April, 1908.—The third period, that of tests and observations in connection with the question of foundations, is dealt with in another paper. It occupied from April, 1907, to November, 1908. The results of the information then gathered was that it was not thought advisable to go on with the foundations.

Period No. 4.—Capping Pile Bores, Sinking Sumps, and Building Cross-Passages.—April, 1908, to November, 1908.—In order to reduce the leakage from the bore segments to the least possible amount before placing the concrete lining, it was decided to remove the plugs and replace them with flat cover-plates; these have been described before, together with the filling of Bore Segments No. 2 with mortar to reduce the leakage around the distance piece.

During this period the turnbuckles to reinforce the broken plates were put in, and the sump sunk at the lowest point of the tunnel. These sumps have been described in a previous part of this paper; they were put down without trouble. As much as possible of the concrete lining was put in before the lining castings were taken into the tunnel, as the space inside was very restricted. The first lining casting was bolted to the flat flanges of the sump segment, the bolts holding the latter to the adjacent segments were removed, and the whole was forced down with two of the old shield jacks, taking a bearing on the tunnel. The two together exerted a pressure of about 150 tons. The plugs in the bottom of the sump segment were taken out, and pipes were put in, through which the silt squeezed up into the tunnel and relieved the pressure on the sump segment.

If the silt did not flow freely, a water-jet was used. The sump was kept plumb by regulating the jacks. In this way the sump was sunk, adding lining sections one by one, and finally putting on the top segment, which was composed of three pieces.

The time taken to sink one sump was about 4 days, working one 8-hour shift per day, and not counting the time taken to set up the jacks and bracing. The sinking of each section took from 4 to 6 hours. The air pressure was 25 lb. and the hydrostatic head 41 lb. per sq. in. The force was 1 assistant superintendent at $6.00 per day, 1 foreman at $4.50, and 6 laborers at $3.00 per day.

Cross-Passages.—It was during this period that the five cross-passages previously mentioned were built. In the case of those in the rock, careful excavation was needed so as to avoid breaking the iron lining. Drilling was done from both ends, the holes were closely spaced, and about 2 ft. 6 in. deep, and light charges of powder were used. The heading, 5 by 7 ft. in cross-section, was thus excavated in five lengths, with 24 holes to a length, and about 23 lin. ft. of hole per yard. About 5.3 lb. of powder per cu. yd. was used. The sides, top, and bottom were then drilled at a very sharp angle to the face and the excavation was trimmed to the right size. This widening out took about 7½ ft. of hole per cu. yd., and 0.9 lb. of powder.

In the passages in silt the excavation had to be 12 ft. wide and 13 ft. 8 in. high to give enough room inside the timbers. The plates at one end of the passage were first removed. An air pressure of 17 lb. was carried, which was enough to keep the silt from squeezing in and yet left it soft enough to be chopped with a spade.

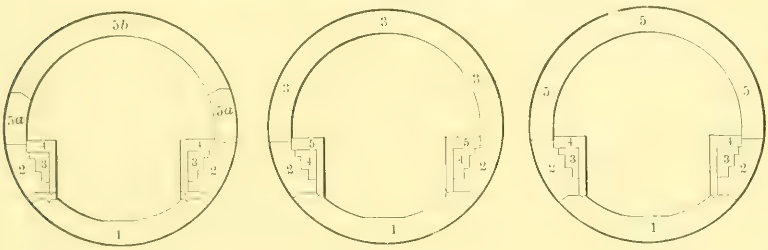
A top heading, of full width and 6 ft. 8 in. high, was first taken out, and the roof was sheathed with 2-in. boards held by 10 by 10-in. head trees at 3-ft. centers, with 10 by 10-in. side trees. The lower 7 ft. of bench was then taken out, a tight floor of 6 by 6-in. cross-timber was put in, and also longer side trees, the head trees being temporarily held by two longitudinal 10 by 10-in. stringers blocked in place. The bulk of the space between the side trees was filled with 10 by 10-in. posts and blocking. The plates at the other end of the passage were then taken out from the other tunnel.

After the excavation was out, the outer reinforced concrete lining was built. Rough forms were used, as the interior surface of the passages were to be rendered with a water-proofing cement. A few

grout pipes were built in, and all voids outside the concrete were grouted. Grouting was also done through the regular grout holes of the metal lining around the openings.

In the case of the most westerly of the cross-passages at Weehawken, which was in badly seamed rock carrying much water, a steel interlining, rather smaller than the concrete, was put in. The space between the concrete and the steel was left open, so that water coming through the concrete lining was stopped by the steel plate. This water was led back to the shield chamber in a special drain laid in the bench of the river tunnel and behind the ducts. From the shield chamber the water ran with the rest of the drainage from the Weehawken Land Tunnels to the Weehawken Shaft sump.

TYPICAL CROSS-SECTIONS SHOWING SUCCESSIVE STAGES IN PLACING CONCRETE IN RIVER TUNNELS



Type 1 Type 2 Type 3

FIG. 21.

Period No. 5.—Placing the Concrete Lining.—November, 1908, to June, 1909.—During the fifth period the concrete lining was put in. This lining was placed in stages, as follows: First, the invert; second, the duct bench; third, the arch; fourth, the ducts; and fifth, the face of the bench. This division can be seen by reference to Fig. 21.

All the work was started on the landward ends and carried toward the middle of the river from both sides. Except where the Weehawken force passed the lowest point of the tunnel, which is at Station 241 or nearly 900 ft. to the west of the middle of the river, all the work was down grade.

Before any concrete was placed, the surface of the iron was cleaned with scrapers and wire brushes, and washed with water. Any leaks in the caulking and grummeting (finished by June, 1907, and therefore all more than 12 months old) were repaired. All the grout hole plugs were examined, and the plugs in any leaking ones were taken out,

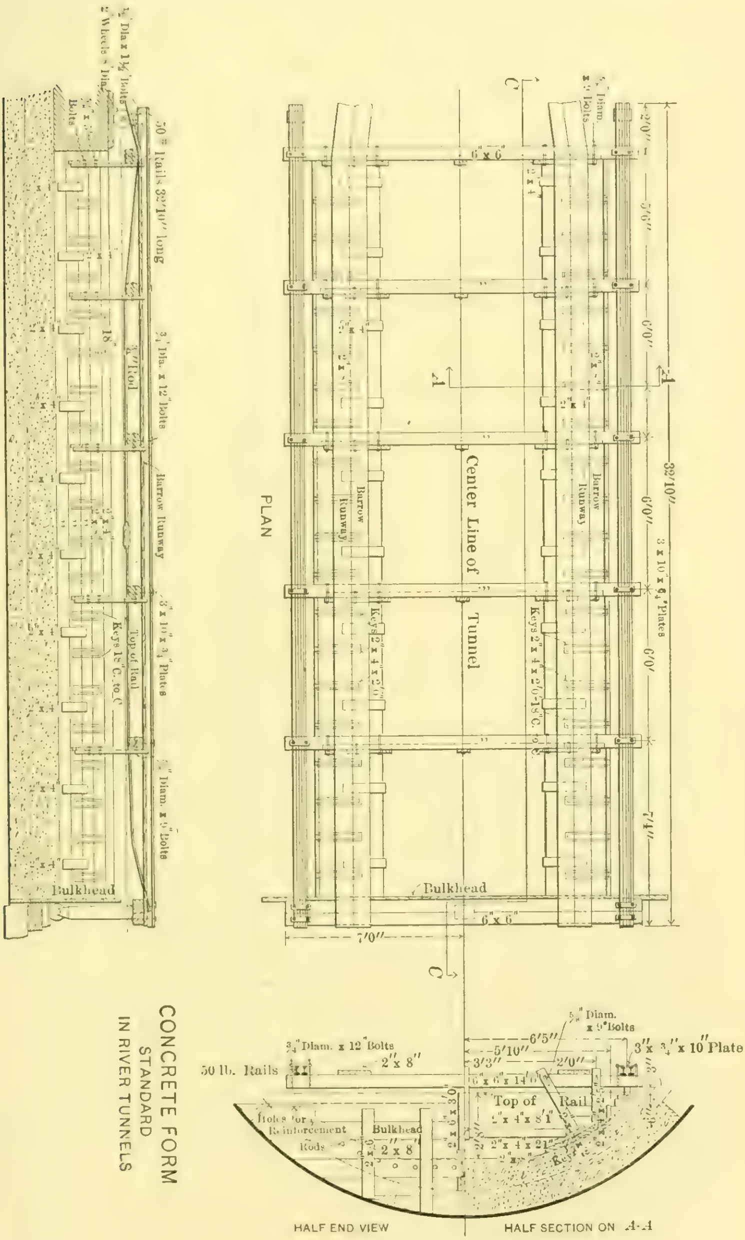
smeared with red lead, and replaced. The leakage in the caulking was due to the fact that the tunnel had been settling slightly during the whole 12 months of pile tests, and, therefore, had opened some of the joints. After the caulking had been repaired and the surface thoroughly cleaned, the flanges were covered with neat cement (put on dry or poured on in the form of thick grout) just before the concrete was placed.

Invert Concrete.—The form used for the landward type of concrete, that is, the one with a middle drain, consisted of a frame made of a pair of trussed steel rails on each side of the tunnel and connected at intervals with 6 by 6-in. cross-timbers; two "wing forms" were hung from this frame by adjustable arms. These wings formed the curved sides of the invert, the lip, and the form for the middle drain. The whole form was supported on three wheels, two on the rear end running on a rail laid on the finished concrete, and the third in front attached to the frame by a carriage and running on a rail temporarily laid on the iron lining. The form was braced from the iron lining by 6 by 6-in. blocks.

For the soft-ground type of invert, namely, the one without the middle drain, a form of the same general type was used, except that the form for the middle drain was removed. After the form had been in use for some time, "key pieces" (made of strips of wood about 1 ft. 3 in. in length and 3 by 3 in. in cross-section) were nailed circumferentially on the under side of the wings at 2-ft. intervals. This was done because, at the time, it was not known whether ballasted tracks or some form of rigid concrete track construction would be adopted, and, if the latter, it was desirable not to have the surface smooth.

The concrete was received in cars at the rear end of the form and dumped on a temporary platform. It was then loaded into wheelbarrows on the runways, as shown in Fig. 22. The concrete was thrown from the barrows into the invert, where it was spaded and tamped.

In cases where there was steel-rod reinforcement, the concrete was first brought up to the level of the underside of these rods, which came between the wings; the rods were laid in place, and then more concrete was placed over the rods and brought up to the level of the bottom of the wings. Where there was no reinforcement, the concrete was brought up in one lift.



CONCRETE FORM
STANDARD
IN RIVER TUNNELS

FIG. 22.

After this was finished, the concrete behind the wings was placed, thoroughly spaded and tamped, and, where there were longitudinal reinforcing rods, these were put in at their proper level. Where there were circumferential rods, the 16-ft. rods had already been put in when the lower part of the concrete was placed. As the invert was being finished off, the 8-ft. rods were embedded and tied in position.

The longitudinal rods were held in place at the leading end of each length of arch by the wooden bulkhead, through which holes were drilled in the proper position. At the rear end they were tied to the rods projecting from the previous length. The quantity of water used in mixing the invert concrete needed very nice adjustment; if too wet, the middle would bulge and rise when the weight of the sides came on it; and, if too dry, it would not pack properly between the flanges of the iron lining. The difficulties as to this were often increased by the flow of accumulated leakage water from the tunnel behind on the concrete while it was being put in. To prevent this, a temporary dam of sand bags was always built across the last length of finished invert concrete before beginning a new length. A sump hole, about 4 by 4 ft. and 1 ft. deep, was left every 800 ft. along the tunnel, and a small Cameron pump was put there to pump out the water.

The invert forms were left in place about 12 hours after the length was finished. The average time taken to fill a length of 30 ft. was 7 hours, the form was then left 12 hours, and it took 2 hours to set it up anew. The total time for one length, therefore, was 21 hours, equal to 34 ft. per 24 hours. At one place, a 45-ft. form was used, and this gave an average speed of 45 ft. per 24 hours.

An attempt was made to build the invert concrete without forms (seeing that a rough finish was desired, as previously explained, to form a key for possible sub-track concrete), but it proved a failure.

The typical working force (excluding transport) was as follows:

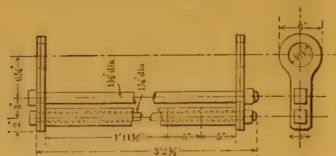
1 Foreman	@	$3.25	per	shift.
2 Spaders	"	2.00	"	"
9 Laborers	"	1.75	"	"

The average time taken to lay a 30-ft. length of invert was 7 hours; the two spaders remained one hour extra, smoothing off the surface.

For setting the form, the force was:

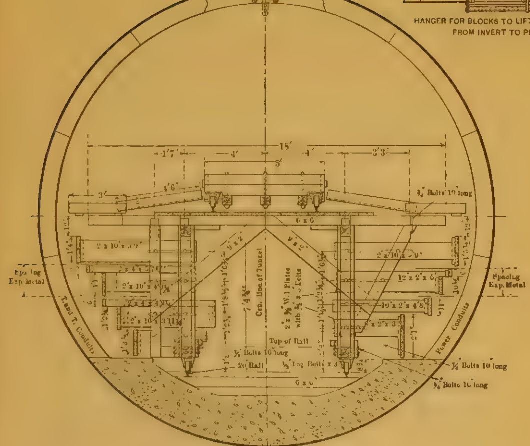
1 Foreman	@	$4.50	per	shift.
5 Carpenters	"	3.25	"	"
6 Carpenters' helpers	"	2.25	"	"

DUCT-BENCH CONCRETE FORM IN RIVER TUNNELS

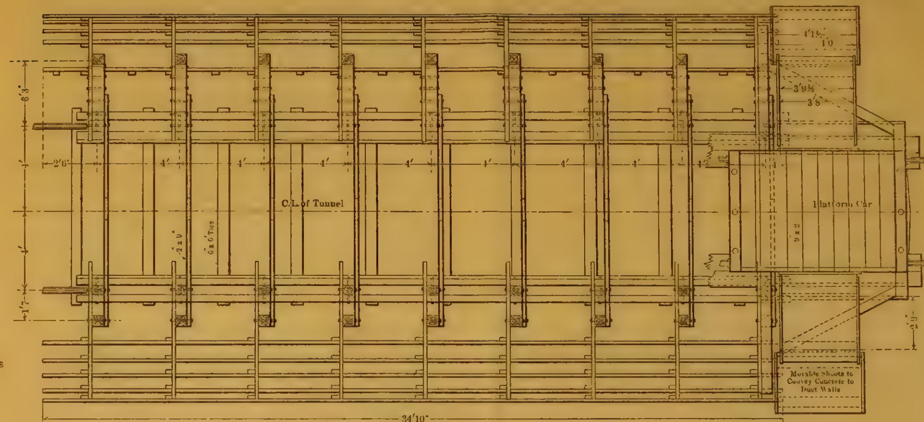


DETAIL VIEW OF HANGER

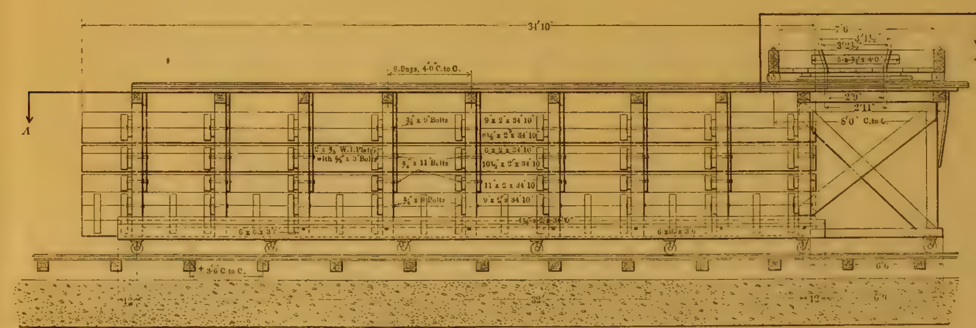
HANGER FOR BLOCKS TO LIFT CONCRETE BUCKETS FROM INVERT TO PLATFORM CAR



EAST END VIEW



PLAN ALONG *AA* (FLOOR SYSTEM NOT SHOWN)



LONGITUDINAL SECTION ON CENTER LINE LOOKING TOWARD POWER CONDUIT BENCH

The average time taken to erect a form was 2 hours, 1 carpenter and 1 helper remaining until the concrete was finished.

Duct Bench Concrete.—The duct bench (as described previously) is the portion of the concrete on which the ducts are laid. The exact height of the steps was found by trial, so as to bring the top of the ducts into the proper position with regard to the top and the face of the bench.

Both kinds of duct bench forms were of the same general type. A drawing of one of them is shown on Plate XCVI. The form consisted of a skeleton framework running on wheels on a track at the level of the temporary transportation tracks. The vertical faces of the steps were formed by boards supported from the uprights by adjustable arms. The horizontal surfaces were formed by leveling off the concrete with a shovel at the top of the vertical boards. Where the sheets of expanded metal used for bonding came at a step, the lower edge of the boards forming the back of the step was placed 1 in. above the one forming the front of it; but, when the expanded metal came in the middle of a step, a slot 1 in. wide was left at that point to accommodate it.

A platform was formed on the top of the framework for the form, and on this a car forming a sort of traveling stage was run. There was ample room to maintain traffic on a single track through the form. A photograph of the form is shown in Fig. 1, Plate XCVII.

The concrete, for the most part, was received at the form in $\frac{3}{4}$-cu. yd. dumping buckets. The buckets were lifted by the rope from a small hoisting engine. This rope passed over a pulley attached to the crown of the tunnel and dumped into the traveling stage on the top of the form. In this the concrete was moved along to the point where it was to be deposited, and there it was thrown out by shovels into the form below. For a portion of the period, while the duct bench concrete was being laid, it was not necessary to maintain a track for traffic through the form and, during that period, the concrete for the lower step was placed from below the form, the concrete being first dumped on a temporary stage at the lower track level.

Owing to the horizontal faces of the steps being uncovered, there was a tendency for the concrete there to rise when concrete was placed in the steps above. For this part of the work, also, it was necessary to see that the concrete was not mixed too wet, for, when that was the case, the concrete in the upper steps was very apt to flow out at the

top of the lower one. At the same time, there was the standing objection to the mixture being too dry, namely, the responsibility of getting a sufficient amount of spading and tamping done. Particulars of the exact quantity of water used are given later in describing "Mixing." Fig. 2, Plate XCVII, illustrates the process of laying.

In the section of the tunnel in which there were circumferential reinforcement rods in the duct bench, the rods were in place before the laying commenced, as they had been placed with the invert concrete. The circumferential reinforcing rods in the arch came down into the upper part of the duct bench concrete; these rods were put in position and tied to the iron lining in the crown at the same time as the duct bench concrete was being finished off. Openings for the manholes were left in the duct bench at the regular stationing.

The average time taken to fill a length of 35 ft. was about 6 hours; the form was then left in position for about 8 hours—usually enough to let the concrete set properly—and then moved ahead; it then took about 3 hours to set it up again ready to continue work. The total time for a length, therefore, was about 17 hours, equal to an average progress of about 49 ft. per day. The average force engaged in duct bench concrete (not including transport) was:

1 Foreman	@	$3.25	per day.
2 Spaders	"	2.00	" "
9 Laborers	"	1.75	" "

Arch Concrete.—By far the greater part of the arch work was put in with traveling centers before the face of the bench was built, in which case the whole of the arch was built at once. A short length of arch at each end of the tunnel was built after the face of the bench, in which case the haunches or lower 5 ft. were laid first and the upper part of the arch later.

The first traveling centers were used on the New York side, and were 50 ft. long. The laggings were of 4-in. yellow pine, built up in panels 10 ft. long and 16 in. wide for the sides, and solely longitudinal lagging 5 ft. long for the key.

It was pretty certain that the results to be obtained from forms of such a length would not be satisfactory, and this was pointed out to the contractor, who, however, obtained permission to use them on trial. Grout pipes were built in, as it was not likely that the concrete could be packed tightly into the upper part of the lining.


A 65. P. R. R. Tunnels. N. R. Div. Sect. Gj. South Tunnel. End view
of portable and adjustable forms for building side bench, concrete
in metal lined tunnels, arranged for putting in duct castings and
expanded metal bonds, looking East from Sta. 267+85.
Dec. 10, 07

FIG. 1.

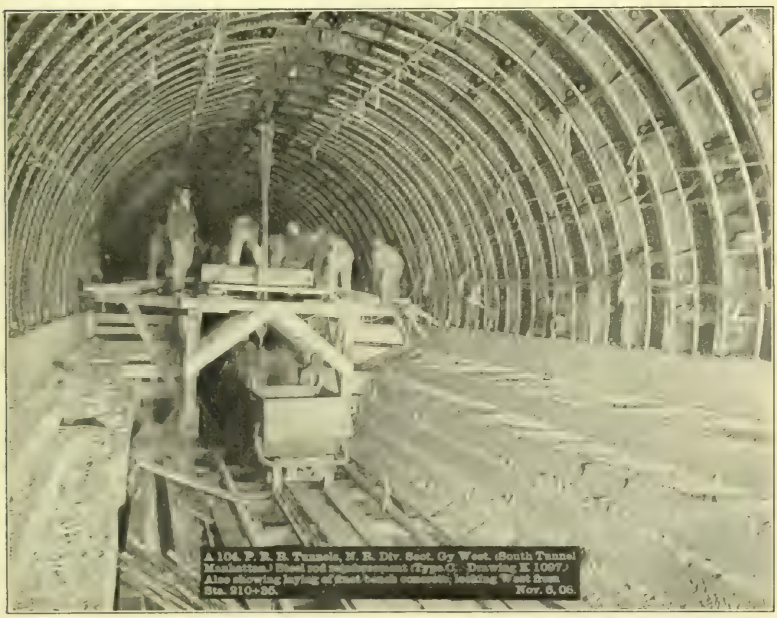

A 104. P. R. R. Tunnels, N. R. Div. Sect. Gy West. (South Tunnel
Manhattan.) Steel rod reinforcement (Type C. Drawing K 1097.)
Sta. 210+35.
Nov. 6, 06.

FIG. 2.

After about 300 lin. ft. of arch had been built with these forms, a test hole was cut out and large voids were found, and, to confirm this, another hole was cut, and similar conditions observed.

The results were so unsatisfactory that orders were given that the use of longitudinal key lagging should be discontinued, and cross or block lagging used instead. These block laggings were 6 in. in length (in the direction of the tunnel) and 2 ft. in width; at the same time, the system of grout pipes was changed. This will be described later under "Grouting." It was soon found that with block lagging a better job could be made of packing the concrete up into the keys, but the time taken to "key up" a 50-ft. length was so great that the rest of the arch had set by the time the key was finished. Despite a lot of practice, this was the case, even in the unreinforced type. When the reinforcing rods were met, the time for keying up became still greater, and therefore the contractor was directed to shorten the forms to 20-ft. lengths. A typical working force for a 50-ft. length was:

1 Foreman	@ $3.25	per	day.
4 Spaders	" 2.00	"	"
12 Laborers	" 1.75	"	"

Details of the 20-ft. forms are shown on Plate XCVIII. The lower 4 ft. of lagging was built on swinging arms, which could be loosened to allow the centers to be dropped and moved ahead. The rest of the lagging was built up in panels 10 ft. long and 1 ft. 4 in. high. The ribs rested on a longitudinal timber on each side; these were blocked up from the top step of the duct bench concrete. When the form was set and when it was released, it was moved ahead on rollers placed under it.

The concrete was received at the form in ¾-cu. yd. dumping buckets; from the flat cars on which they were run, these were hoisted to the level of the lower platform of the arch form. At this level the concrete was dumped on a traveling car or stage, and moved in that to the point on the form where it was to be placed. For the lower part of the arch, the concrete was thrown directly into the form from this traveling stage, but, for the upper part, it was first thrown on the upper platform of the arch. The hoisting was done by a small Lidgerwood compressed-air hoister, and set up on an overhead platform across the tunnel. The pulley over which the cable from the hoister passed was attached to the iron lining near one end of the form, and the traveling stage ran back

from the arch form on a trailer, shown on Plate XCVIII. When it was impossible to hang a pulley—owing to the concrete arch having been built at the point where the trailer stood—an **A**-frame was built on the trailer, and the pulley was attached to that.

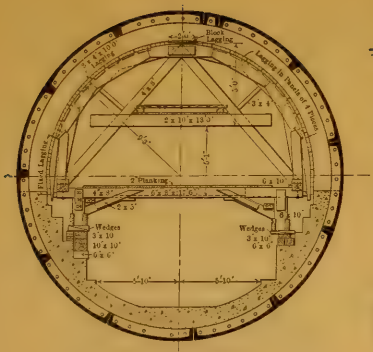
In laying the lower part of the arch, about 1 ft. of lagging (including the swinging arms) was first set, the other panels being pulled up toward the top of the arch. When that was filled, the next panel above was lowered into place, and the work continued. As the concrete rose toward the key, it was packed up to a radial surface, so that the arch would not be unduly weakened if the sides set before the key was placed. All the time, great care was taken to see that the concrete was carefully packed into the segments of the metal lining. The quantity of water used in the concrete was carefully regulated, more being used in the lower than in the upper parts of the arch.

In places where there were no reinforcing rods, the width of the concrete key was the length of the block lagging, namely, 2 ft. Where there was circumferential reinforcement, the key had to be more than 5 ft. wide, in order to take the 5-ft. closure rods used in the key. This naturally increased the time of keying very much. On the places where the 5-ft. longitudinal laggings were used, it was impossible to fill the flanges of the metal lining much higher than their undersides.

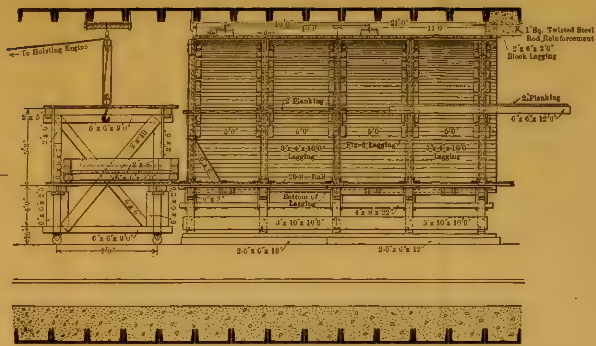
As the concrete used in the key had to be much drier than that used elsewhere, it was not easy to get a good surface. This trouble was overcome by putting a thin layer of mortar on the laggings just before the concrete was put in.

The overhead conductor pockets were a great hindrance to the placing of the key concrete, especially where the iron was below true grade. Whenever an especially troublesome one was met, a special grout pipe was put in to fill up unavoidable holes by grouting after the concrete had set. All the circumferential reinforcing rods were bent in the tunnel by bending them around a curved form of less diameter than the required bend. This generally left them all right in the middle of their length, but with their end portions too straight; in such cases the ends were bent again. All rods were compared with a template before being passed for use.

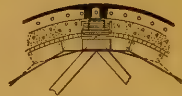
The arch forms were left up for 48 hours after keying was finished. Levels taken after striking the forms showed that no appreciable settlement occurred. An average gang for a 20-ft. length of arch was:



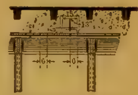
END VIEW OF ARCH FORM
LOOKING WEST



LONGITUDINAL SECTION ON CENTER LINE
LOOKING NORTH

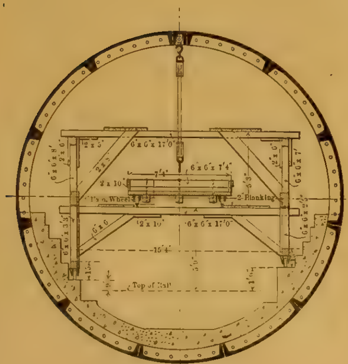


CROSS-SECTION

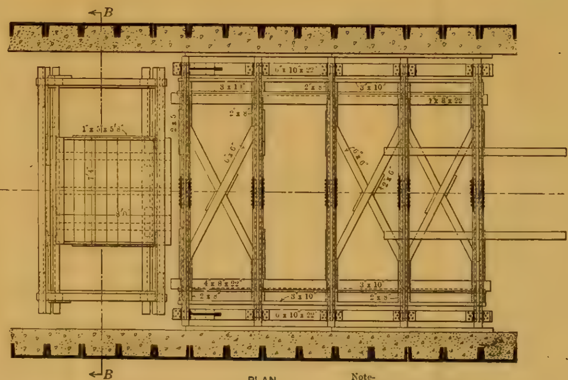


LONGITUDINAL SECTION

DIFFERENT ARRANGEMENT OF
GROUT AND VENT PIPES
USED FOR GROUTING IN RIVER
TUNNELS BETWEEN CONCRETE
ARCH AND IRON LINING



SECTION B-B



PLAN

Note-
Top and Bottom Floors
not shown

1 Foreman	@	$3.25	per shift.
2 Spaders	"	2.00	" "
10 Laborers	"	1.75	" "

Table 30 shows the progress attained under various conditions.

Whenever the face of the bench concrete was constructed before the arch, the latter was built in two separate portions, that is, the bottom 5 ft., or "haunches" of the arch, as they were termed, were built on each side and the rest of the arch later. This involved the use of two separate sets of forms, namely, for the haunch and for the arch. Not very much arch was built in this way, and, as the methods were in principle precisely the same as those used when all the arch was built in one operation, no detailed description is needed.

No provision was made in the contract for grouting the concrete arch, but it soon became evident that by ordinary methods the top part of the concrete could not be packed solid against the iron segments, especially in the keys. As it was imperative to have the arch perfectly solid, it was determined to fill these unavoidable gaps with a 1 : 1 Portland cement grout, at the same time making every effort to reduce the spaces to a minimum. This made it necessary to build grout pipes into the concrete as it was put in.

The first type of grout pipe arrangement is shown as Type *A*, in Fig. 23. This was used with the longitudinal key laggings; when this method was found to be no good, and cross-laggings were used, the system shown as Type *B*, in Fig. 23, was adopted, in which vents were provided to let out the air during grouting. The expense of these pipes was high, and the contractor obtained permission to use sheet-iron tubes, which, however, were found to be unsuitable, so that the screwed pipes were used again. The contractor next obtained permission to try dispensing altogether with the vent pipes, and so Type *C*, in Fig. 23 was evolved. This, of course, was found to be worse than any of the other systems, as the imprisoned air made it impossible to force grout in. Several other modifications were made, and are shown in Fig. 23.

It was then decided to devise as perfect a system as possible, without allowing the question of cost to be the ruling factor, and to use that system throughout. In this system, shown as Type *S*, in Fig. 23, most of the vent pipes were contained in the concrete, and their size was independent of the thickness of the arch, so that they were easily

TABLE 30.—Average Time Taken for Various Operations Connected with Building Concrete Arches in Subaqueous Tunnels.

Average time, in hours, form stood after filling.	Type of reinforcement.	Length of section, in feet.	Time, in hours, moving and erecting forms.		Time, in hours, placing concrete in arch.	Time, in hours, placing concrete in key.	Time, in hours, placing concrete in key and arch.	Total time, in hours, for moving, erecting, and filling.	Total time, in hours, per linear foot, for moving, erecting, and filling.	Remarks.
70	A day work	50	20		15	15.40	30.40	50.40	1.01	......
			Moving	Erecting						
..	A day work	20	2	3	8.30	2.40	11.10	16.10	0.80	......
53	B day work	20	2	3	10.40	11.20	22.00	27.00	1.35	Includes placing rods.
53	C day work	20	2	3	11.00	7.20	18.20	23.20	1.16	do.
53	D day work	20	2	3	9.50	4.35	14.25	19.25	0.91	do.
53	D piece work	20	2	3	6.15	2.05	8.20	13.20	0.65	do.
53	Sub-Type No. 1 piece work	20	2	3	6.00	3.00	9.00	14.00	0.70	do.

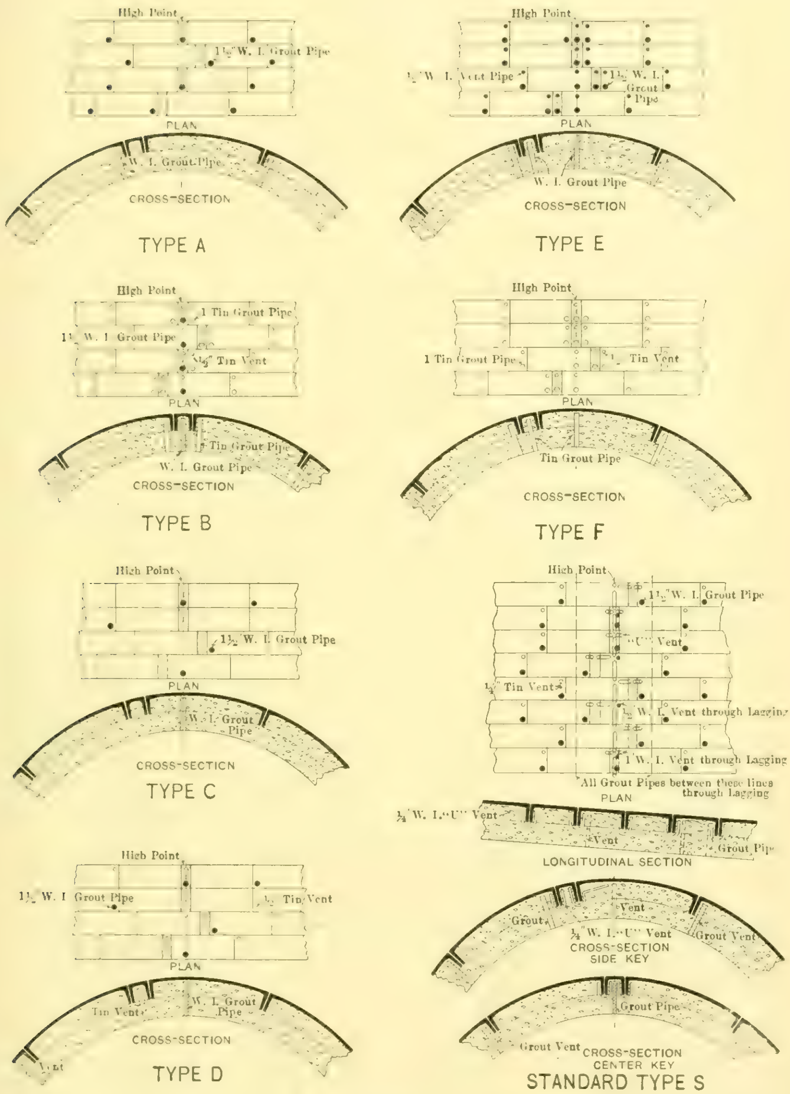

High Point
1½" W. I. Grout Pipe
PLAN
W. I. Grout Pipe
CROSS-SECTION
TYPE A
High Point
W. I. Vent Pipe
1½" W. I. Grout Pipe
PLAN
W. I. Grout Pipe
CROSS-SECTION
TYPE E
High Point
1 Tin Grout Pipe
1½" W. I. Grout Pipe
½" Tin Vent
PLAN
Tin Grout Pipe
W. I. Grout Pipe
CROSS-SECTION
TYPE B
High Point
1 Tin Grout Pipe
Tin Vent
PLAN
Tin Grout Pipe
CROSS-SECTION
TYPE F
High Point
1½" W. I. Grout Pipe
PLAN
W. I. Grout Pipe
CROSS-SECTION
TYPE C
High Point
1½" W. I. Grout Pipe
"U" Vent
¼" Tin Vent
W. I. Vent through Lagging
1" W. I. Vent through Lagging
All Grout Pipes between these lines through Lagging
PLAN
¾" W. I. "U" Vent
Vent
Grout Pipe
LONGITUDINAL SECTION
Vent
Grout
¾" W. I. "U" Vent
Grout Vent
CROSS-SECTION SIDE KEY
Grout Pipe
Grout Vent
CROSS-SECTION CENTER KEY
STANDARD TYPE S
High Point
1½" W. I. Grout Pipe
Tin Vent
PLAN
Tin Vent
W. I. Grout Pipe
CROSS-SECTION
TYPE D

FIG. 23.

fixed in position and not subject to disturbance while placing the concrete. This system was used for about 80% of the total length of the tunnel, and proved entirely satisfactory. The machine used for grouting was the same as that used for grouting outside the metal lining.

The only compressed air available was the high-pressure supply, at about 90 lb.; a reducing valve, to lower this pressure to 30 lb. was used between the air line and the grouting machine. This was thought to be about as high a pressure as the green concrete arch would stand, and, even as it was, at one point a section about 2 ft. by 1 ft. was blown out.

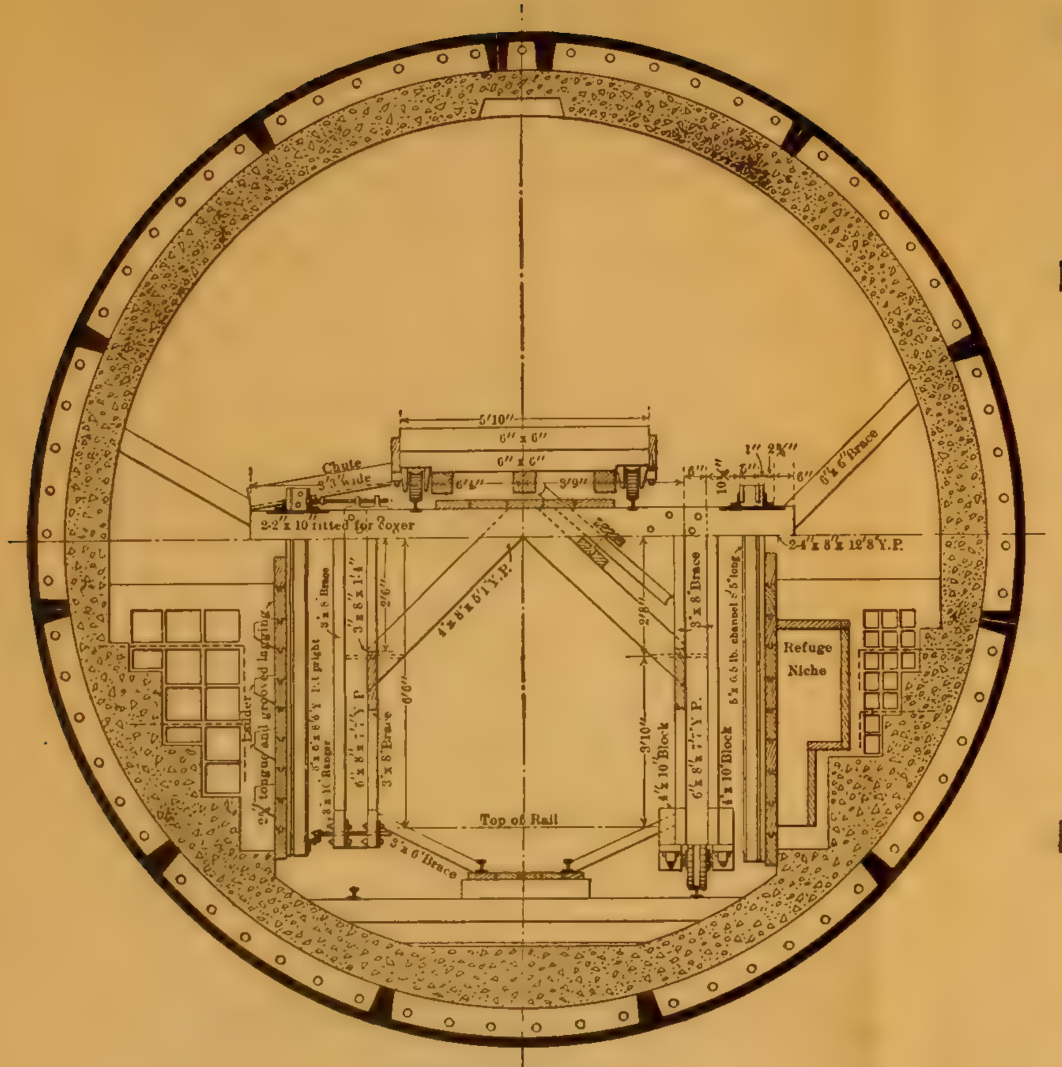
A rough traveling stage resting on the bottom step of the duct bench concrete was used as a working platform. In the earlier stages of the work the grouting was carried on in a rather haphazard manner, but, when the last system of grout and vent pipes was adopted, the work was undertaken systematically, and was carried out as follows:

Two 20-ft. lengths of arch were grouted at one time, and, in order to prevent the grout from flowing along the arch and blocking the pipes in the next lengths, a bulkhead of plaster was made at the end of every second length to confine the grout.

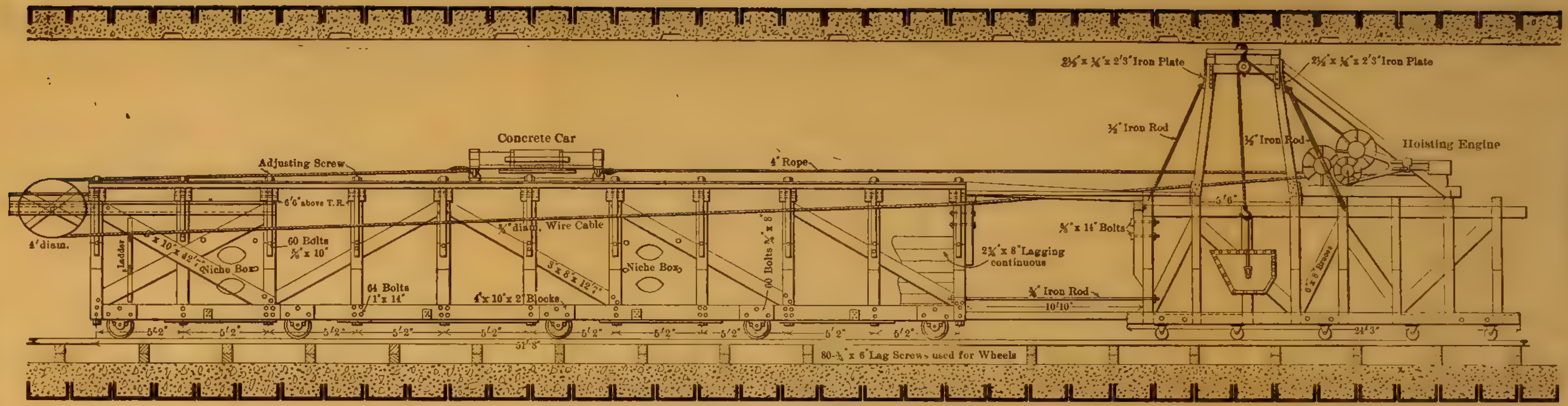
After a section had been grouted, test holes were drilled every 50 ft. along the crown to see that all the voids were filled; if not, holes were drilled in the arch, both for grouting and for vents, and the faulty section was re-grouted. An average of ¾ bbl. of cement and an equal quantity of sand was used per linear foot of tunnel. The average amount put in by one machine per shift was 15 bbl., and therefore the average length of tunnel grouted per machine per shift was 20 ft. The typical working force was:

1 Foreman	@ $3.75	per	shift
1 Laborer running grout machine	" 2.00	"	"
2 Laborers handling cement and sand	" 1.75	"	"
1 Laborer tending valve and grout pipes	" 1.75	"	"

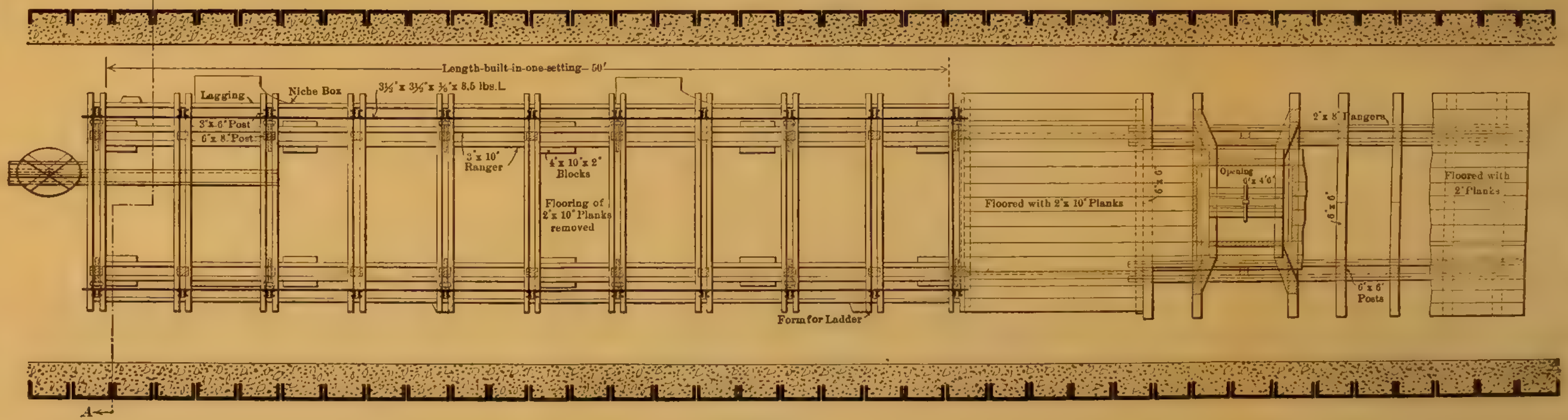
After the grouting was finished, the arches were rubbed over with wire brushes to take off discoloration, and rough places at the junctions of adjoining lengths or left by the block laggings were bush-hammered.



CROSS-SECTION ON A-A

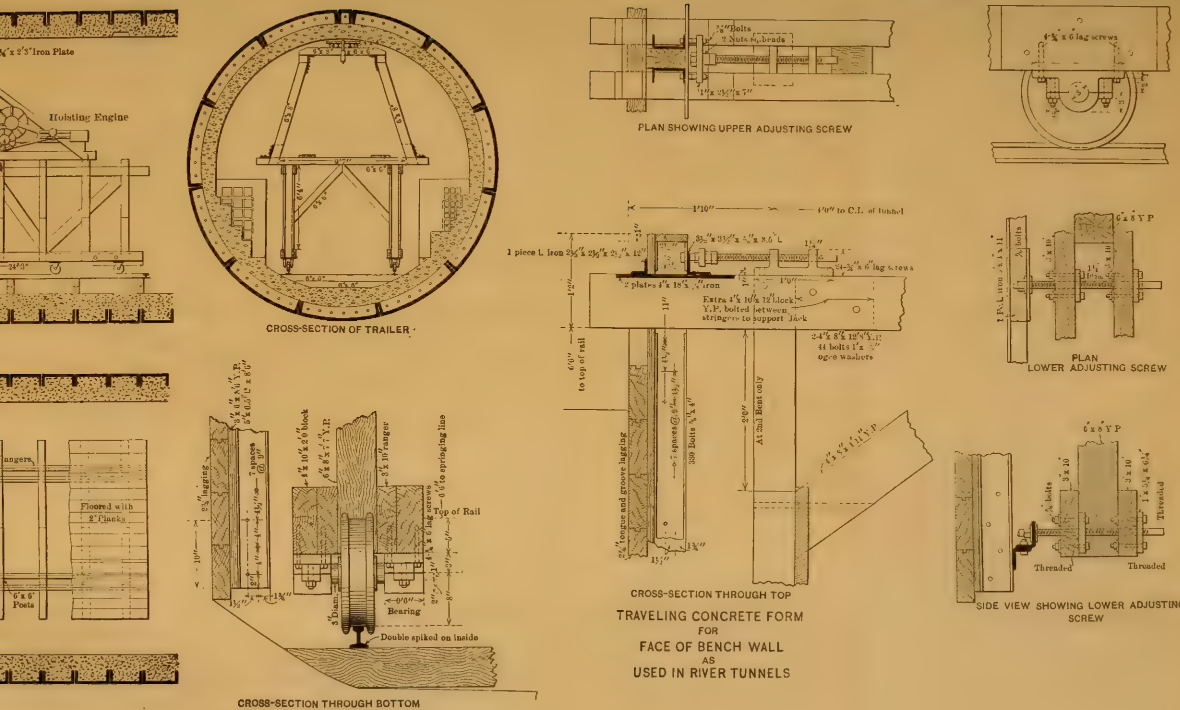


LONGITUDINAL SECTION



PLAN

PLATE XCIX.
PAPERS, AM. SOC. C. E.
APRIL, 1910.
HEWETT AND BROWN ON
PENN. R. R. TUNNELS: THE NORTH RIVER TUNNELS.



TRAVELING CONCRETE FORM
FOR
FACE OF BENCH WALL
AS
USED IN RIVER TUNNELS

Face of Bench Concrete. The form used for this portion of the work is shown on Plate XCIX. It consisted of a central framework traveling on wheels, and, from the framework, two vertical forms were suspended, one on each side, and equal in height to the whole height of the bench. Adjusting screws were fitted at intervals both at top and bottom, and thus the position of the face forms could be adjusted accurately. The face forms were built very carefully of 3-in. tongued and grooved yellow pine, and one 50-ft. form was used for 3 000 ft. of tunnel without having the face renewed. Great care was taken to set these forms true to line and grade, as the appearance of the tunnel would have been ruined by any irregularity. Joints between successive lengths were finished with a V-groove.

The concrete was received at the form in dumping buckets; these were hoisted to the top of the form by a Lidgerwood hoister fixed to a trailer. The concrete was placed in the form by shoveling it from the traveling stage down chutes fitted to its side. The quantity of water to be used in the mixture needed careful regulation. The first few batches in the bottom had to be very wet, and were made with less stone than the upper portion, in order that the concrete would pack solidly around the niche box forms and other awkward corners.

The forms for the ladders and refuge niches were fastened to the face of the bench forms by bolts which could be loosened before the main form was moved ahead, and in this way the ladder and niche forms were left in position for some time after the main form was removed.

At first the forms were kept in place for 36 hours after finishing a length, but, after a little experience, 24 hours was found to be enough. In the summer, when the rise of temperature quickened the set, the time was brought down to 18 hours. The average time taken for a 50-ft. length was:

Laying concrete	4½	hours.
Interval for setting	18	"
Moving forms ahead and resetting	5	"
Total	27½	hours.

The typical working gang was:

Laying Concrete.

1 Foreman	@ $3.25	per	shift.
2 Spaders	" 2.00	"	"
8 Laborers	" 1.75	"	"

Moving and Setting Forms.

1 Foreman	@ $4.00	per	shift.
10 Laborers	" 1.75	"	"

After the forms were removed, any rough places at the lower edge, where the concrete joins the "lip," were bush-hammered; no other cleaning work was done.

Duct Laying and Rodding.—The design and location of the ducts have already been described. It will have been seen that the duct-bench concrete was laid in steps, on which the ducts were laid, hence the maintenance of the grade and line in the ducts was an easy matter. The only complication was the expanded metal bonds, which were bent up out of the way of the arch forms and straightened out again after the arch forms had passed. The materials, such as ducts, sand, and cement, were brought into the tunnel by the regular transportation gang. The mortar was mixed in a wooden trough about 10 ft. long, 2 ft. 6 in. wide and 8 in. deep.

After the single-way ducts had been laid, all the joints were plastered with mortar, in order to prevent any foreign substance from entering the ducts. This was not necessary with the multiple duct, as the joints were wrapped with cotton duck. The ducts were laid on a laying mandrel, and, as soon as possible after the concrete was laid around a set of ducts, they were "rodded" with a rodding mandrel. Not many obstructions were met, and these were usually some stray laying mandrel which had been left in by mistake, or collections of mortar where the plastering of the single-way joints had been defective.

In the 657 000 duct ft. of conduit in the river tunnels only eight serious obstructions were met. That the work was of exceptionally high quality is shown by the fact that a heavy 3-in. lead cable has been passed through from manhole to manhole (450 ft.) in 6 min., and the company, engaged to lay the cables in these ducts, broke all its previous records for laying, not only for tunnel work, but also in the open.

Fig. 1, Plate LXXXIX, shows a collection of the tools and arrangements used in laying and rodding ducts. The typical working force was:

Laying Multiple Ducts.

1 Foreman	@ $3.50	per	shift.
9 Laborers	" 1.75	"	"

Laying Single-Way Ducts.

1 Foreman	@	$3.50	per	shift.
8 Laborers	"	1.75	"	"

Rodding Multiple Ducts.

1 Foreman	@	$3.50	per	shift.
5 Laborers	"	1.75	"	"

Rodding Single-Way Ducts.

1 Foreman	@	$3.50	per	shift.
5 Laborers	"	1.75	"	"

The average progress per 10-hour shift with such gangs was:

Laying multiple ducts	4 000	duct	ft.
Laying single-way ducts	1 745	"	"
Rodding multiple ducts	4 040	"	"
Rodding single-way ducts	2 532	"	"

No detailed description need be given of the concreting of the cross-passages, pump chambers, sumps, and other small details, the design of which has been previously shown. The concrete was finished on June 1st, 1909.

Period No. 6.—Final Cleaning Up.—June, 1909, to November, 1909.—As soon as all the concrete was finished, the work of cleaning up the invert was begun. A large quantity of débris littered the tunnels, and it was economical to remove it as quickly as possible. The remaining forms were first removed, and hoisting engines, supported on cross-timber laid across the benches, were set up in the middle of the tunnel at about 500-ft. intervals.

Work was carried on day and night, and about 169 ft. of single tunnel was cleared per 10-hour shift. Work was begun on May 28th, and finished on July 15th, 1909. For part of the time it was carried on at two points in each tunnel, working toward the two shafts, but when the work in the Weehawken Shaft, which was being done at the same time, blocked egress from that point, all material was sent out by the Manhattan Shaft.

The total quantity of material removed was 5 350 cu. yd., or about 0.44 cu. yd. per lin. ft. of tunnel. The average force per shift was:

In Tunnel.

3 Foremen	@	$3.25	per	shift
1 Hoist engineer	"	3.00	"	"
1 Signalman	"	2.00	"	"
38 Laborers	"	1.75	"	"

On the Surface.

1 Foreman	@	$3.25	per	shift
1 Hoist engineer	"	3.00	"	"
1 Signalman	"	2.00	"	"
12 Laborers	"	1.75	"	"

After the cleaning out had been done, the contractor's main work was finished. However, quite a considerable force was employed, up to November, 1909, in doing various incidental jobs, such as the installation of permanent ventilation conduits and nozzles at the intercepting arch near the Manhattan Shaft, the erection of a headhouse over the Manhattan Shaft, and collecting and putting in order all the miscellaneous portable plant, which was either sold or returned to store, sorting all waste materials, such as lumber, piping, and scraps of all kinds, and, in general, restoring the sites of the working yards to their original condition.

Concrete Mixing.

The plant used in mixing the concrete for the land tunnels was pulled down and re-erected before the concrete work in the river tunnels was begun. At the New York shaft two new bins for sand and stone were built, bringing the total capacity up to 950 cu. yd. Two No. 6 Ransome mixers, driven electrically by 30-h.p. General Electric motors, using current from the contractor's generators, were set up on a special platform in the intercepting arch.

At Manhattan the sand and stone were received from the bins in chutes at a small hopper built on the permanent upper platform of the intercepting arch. Bottom-dumping cars, divided by a partition into two portions, arranged to hold the proper quantities of sand and stone for a 4-bag batch of concrete, were run on a track on this upper platform, filled with the proper quantities of sand and stone, and then run back and dumped into the hoppers of the mixer. After mixing, the batch was run down chutes into the tunnel cars standing on the track below. The water was brought in pipes from the public supply. It was measured in barrels by a graduated scale within the barrels. The water was not put into the mixer until the sand and stone had all run out of the mixer hopper. The mixture was revolved for about 1½ min., or about 20 complete revolutions.

At Weehawken Shaft the mixing plant was entirely rebuilt. Four

large bins, two for sand and two for stone, were built in the shaft. Together, they held 430 cu. yd. of stone and 400 cu. yd. of sand. The sand and stone were dumped directly into the bins from the cars on the trestle which ran from the wharf to the shaft. The materials were run through chutes directly from the bins to the hoppers of the mixers, where they were measured. Two No. 6 Ransome mixers, electrically driven, were used here, as at New York, and, as there, the water was led into measuring tanks before being let into the mixer.

The quantity of water used in the various parts of the concrete cross-section, for a 4-bag batch consisting of 1 bbl. (380 lb.) of cement, 8.75 cu. ft. of sand, and 17.5 cu. ft. of stone, is given in Table 31.

TABLE 31.—Quantity of Water per 4-Bag Batch of Concrete, in U. S. Gallons.

Portion of cross-section.	Maximum.	Minimum.	Average.
Invert	40	20	26
Duct bench	36	21	27
Arch (excluding key)	37	19	25
Key of arch	27	15	20
Face of bench	31	22	27

The maximum quantities were used when the stone was dry and contained more than the usual proportion of fine material, the minimum quantity when the sand was wet after rain.

The resulting volumes of one batch, for various kinds of stone, are given in Table 32.

TABLE 32.—Volume of Concrete per Batch, with Various Kinds of Stone.

Mixture.	Description of Stone.		Resulting volume per barrel of cement, in cubic yards.	Remarks.
	Passed screen.	Retained on screen.		
1 : 2½ : 5	1½-in.	⅜-in.	0.815	Measured in air.
1 : 2½ : 5	2½-in.	Run of crusher.	0.827	" " "
1 : 2½ : 5	....	General average.	0.808*	Measured from plan.
1 : 2½ : 5	2-in.	1½-in.	0.768†	" " "

* Average for whole of River Tunnel section.

† Average from 7 400 cu. yd. in Land Tunnel section.

The sand used was practically the same for the whole of the river tunnel section, and was supposed to be equal to "Cow Bay" sand. The result of the mechanical analysis of the sand is shown on Plate C. The stone was all trap rock. For the early part of the work it consisted of stone which would pass a 2-in. ring and be retained on a 1½-in. ring, in fact, the same as used for the land tunnels. This was found to be too coarse, and for a time it was mixed with an equal quantity of fine gravel or fine crushed stone. As soon as it could be arranged, run-of-crusher stone was used, everything larger than 2½ in. being excluded. About three-quarters of the river tunnel concrete was put in with run-of-crusher stone. The force was:

At Manhattan.

1 Foreman	@ $3.00	per	shift
4 Men on sand and stone cars	" 1.75	"	"
4 Men handling cement	" 1.75	"	"
2 Men dumping mixers	" 1.75	"	"

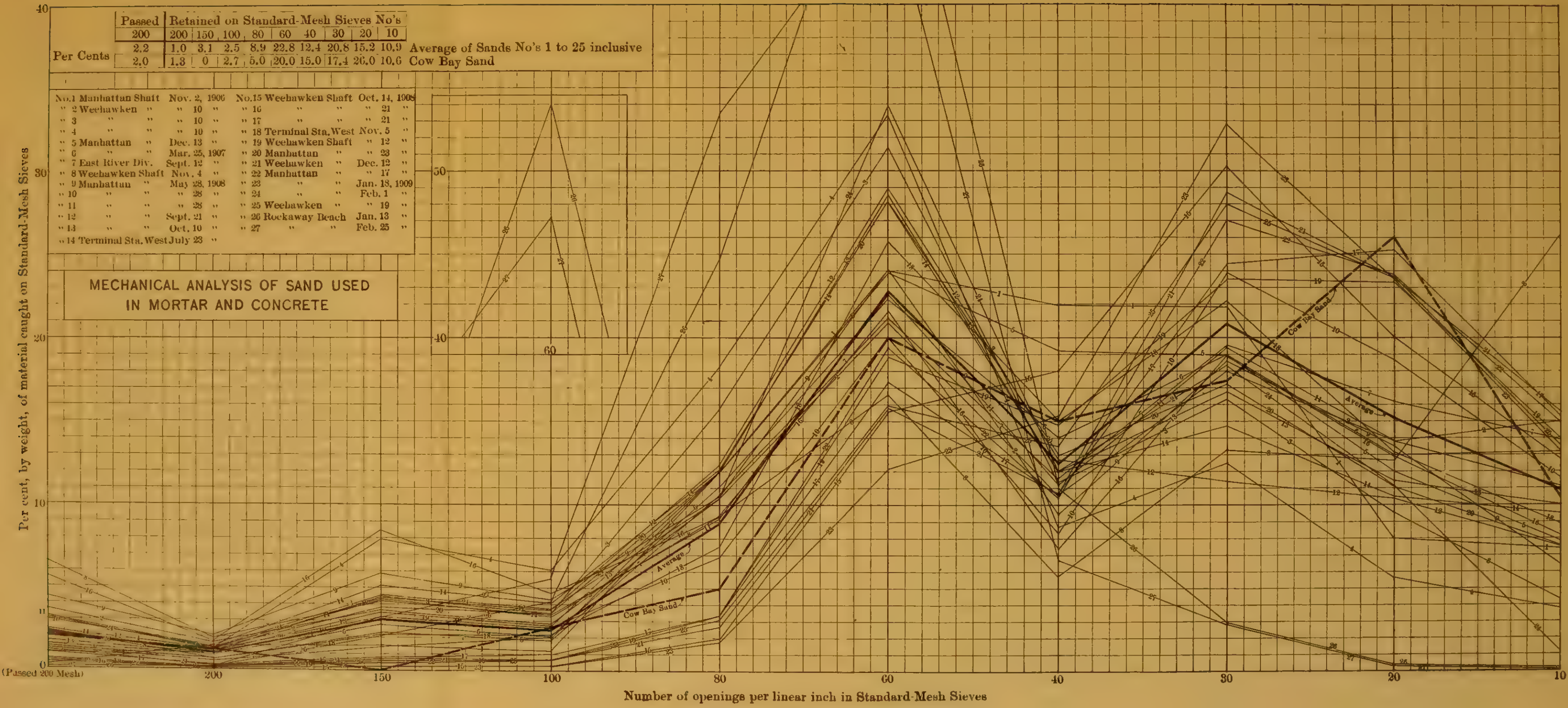
At Weehawken.

1 Foreman	@ $3.00	per	shift
2 Men hauling cement	" 1.75	"	"
2 Men dumping mixers	" 1.75	"	"

The average quantity of concrete mixed per 10-hour shift was about 117 batches, or about 90 cu. yd. The maximum output of one of the mixers was about 168 batches, or 129 cu. yd. per 10-hour shift.

Transportation.

Surface Transportation.—At Manhattan the stone and sand were received in scows at the wharf on the river front. For the first part of the work, the wharf at 32d Street and North River was used, and while that was in use the material was unloaded from the scows into scale-boxes by a grab-bucket running on an overhead cable, and then teamed to the shaft. For the latter part of the work, the wharf used was at 38th Street and North River, where facilities for unloading were given to the contractor by the Pennsylvania Railroad Company which was the permanent lessee of the piers. The material was unloaded into scale-boxes by a grab-bucket operated by a derrick, and teamed to the shaft. When the scale-boxes arrived at the shaft they were lifted from the trucks by derricks and dumped into the bins.


MECHANICAL ANALYSIS OF SAND USED
IN MORTAR AND CONCRETE
Passed
Retained on Standard-Mesh Sieves No's
200 | 200 | 150 | 100 | 80 | 60 | 40 | 30 | 20 | 10
Per Cents
2.2 | 1.0 | 3.1 | 2.5 | 8.9 | 22.8 | 12.4 | 20.8 | 15.2 | 10.9 Average of Sands No's 1 to 25 inclusive
2.0 | 1.3 | 0 | 2.7 | 5.0 | 20.0 | 15.0 | 17.4 | 26.0 | 10.6 Cow Bay Sand
No.1 Manhattan Shaft Nov. 2, 1906
" 2 Weehawken " " 10 "
" 3 " " " 10 "
" 4 " " " 10 "
" 5 Manhattan " Dec. 13 "
" 6 " " Mar. 25, 1907
" 7 East River Div. Sept. 12 "
" 8 Weehawken Shaft Nov. 4 "
" 9 Manhattan " May 28, 1908
" 10 " " " 28 "
" 11 " " " 28 "
" 12 " " Sept. 21 "
" 13 " " Oct. 10 "
" 14 Terminal Sta. West July 23 "
No.15 Weehawken Shaft Oct. 14, 1908
" 16 " " " 21 "
" 17 " " " 21 "
" 18 Terminal Sta. West Nov. 5 "
" 19 Weehawken Shaft " 12 "
" 20 Manhattan " " 23 "
" 21 Weehawken " Dec. 12 "
" 22 Manhattan " " 17 "
" 23 " " Jan. 18, 1909
" 24 " " Feb. 1 "
" 25 Weehawken " " 19 "
" 26 Rockaway Beach Jan. 13 "
" 27 " " Feb. 25 "
Average
Cow Bay Sand
Per cent, by weight, of material caught on Standard-Mesh Sieves
Number of openings per linear inch in Standard-Mesh Sieves
(Passed 200 Mesh)
200
150
100
80
60
40
30
20
10
0
10
20
30
40
50

At Weehawken all the stone and sand, with the exception of the stone crushed on the work, was received by water at the North slip. Here it was unloaded by a 2-cu. yd. grab-bucket and dumped into 3-cu. yd. side-tipping cars, which were hauled by a small steam locomotive over the trestle to the shaft, where they were dumped directly into the bins.

Before beginning the concrete lining, the 2-ft. gauge railway, which had been used for the surface transportation during the driving of the iron-lined tunnels, was taken up and replaced by a 3-ft. gauge track consisting largely of 30-lb. rails. The cars were 3-cu. yd. side-dumping, with automatic swinging sides. Two steam locomotives which were being stored at Weehawken (part of the plant from another contract), were used for hauling the cars in place of the electric ones used with the 2-ft. gauge railway.

Tunnel Transport.—The track used in the tunnel was of 2-ft. gauge, laid with the 20-lb. rails previously used in driving the iron-lined tunnels. The mining cars (previously mentioned in describing the driving of the iron-lined tunnels) were used for transporting the invert concrete, although, for most of the work, lumping buckets carried on flat cars were used. Several haulage systems were considered for this work, but not one of them was thought to be flexible enough to be used with the constantly changing conditions, and it was eventually decided to move all the cars by hand, because, practically all the work being down grade, the full cars could be run down by gravity and the empty ones pushed back by hand. Two men were allotted to each car, and were able to keep the traffic moving in a manner that would have been perhaps impossible with any system of mechanical haulage. This system was apparently justified by the results, for the whole cost of the tunnel transport, over an average haul of about 2 000 ft., was only about 50 cents per cu. yd., which will be found to compare favorably with mechanical haulage on similar work elsewhere, provided full allowance is made for the use of the plant and power.

Force Employed.—The average force employed on transport, both on the surface and in the tunnel, is shown in Table 33.

Costs.

During the work, careful records of the actual cost to the contractor of carrying out this work were kept by the Company's forces; these

costs include all direct charges, such as labor and materials, and all indirect charges such as head office, plant depreciation, insurance, etc., but do not include the cost of any financing, of which the Company had no information.

TABLE 33.—AVERAGE FORCE PER SHIFT FOR TRANSPORTATION IN TWO TUNNELS.

Location.	Grade.	Rate.	Work in Progress.		
			Two inverts and two duct benches.	Two arches, two inverts, and two duct benches.	Four arches and one face of bench.
Tunnel...	Foreman............	$3.00	2	2	2
	Laborer.............	1.75	24	28	70
	Switchmen..........	2.00	..	2	2
	Hoisting engineers.	3.00	2	4	5
Surface..	Foreman............	3.00	1	1	2
	Laborers............	1.75	8	8	15
	Teams..............	6.50	1	1	2

Field Engineering Staff.

The field staff may be considered as divisible into five main divisions:

(*A*).—Construction, including alignment,

(*B*).—Cost records,

(*C*).—Testing of cement and other materials of construction,

(*D*).—Photography,

(*E*).—Despatch-boat service.

(*A*).—*Construction* (*Inspection and Alignment*) *Staff.*—A comparatively large staff was maintained by the Company, and to this two causes contributed. In the first place, the contractor maintained no field engineering staff, because, early in the proceedings, it was arranged that the Company would carry out all this work, and thus avoid the overlapping, confusion, and lack of definite responsibility which often ensues when two engineering forces are working over the same ground. Even had the contractor maintained an engineering force, it would have been necessary for the Company to check most of the contractor's work.

In the second place, this work gave rise to a number of special surveys, tests, borings, and observations of various kinds, most of which were kept up as a part of the regular routine work, and this necessi-

tated a staff. Also, for a whole year, active progressive work was at a standstill while the pile tests were going on.

(*B*).—*Cost Records Staff.*—A distinct feature was made of keeping as accurately as possible detailed records of the actual cost to the contractor of carrying out the work. A small staff of clerks, retained solely for this purpose, tabulated and recorded the information furnished by the members of the construction staff. About $12 000, altogether, was spent in salaries in this department, and it may be considered an extremely wise investment, for, not only is the information thus obtained of great value and interest in itself, but it also puts the Company in an excellent position should any claim or discussion arise with the contractor.

(*C*).—*Cement-Testing Department.*—As the Company furnished the cement to the contractor, it became incumbent to make careful tests of the quality. A cement-testing laboratory was established at the Manhattan Shaft offices, under the charge of a cement inspector who was furnished with assistants for sampling, shipping, and testing cement. All materials used on the work, such as bricks, sand, stone, water-proofing, etc., were tested here, with the exception of metals, which were under the charge of a metal inspector reporting directly to the head office. This department cost about $10 000 for salaries and $3 000 for apparatus and supplies, or about $13 000, in all.

There were 800 000 bbl. of cement tested, and samples from 2 100 000 brick. A large amount of useful information has resulted from the work of this laboratory.

(*D*).—*Photography.*—It was desired to keep a complete photographic record of the progress of the work, and therefore a photographer was appointed, with office room at the Manhattan Shaft. The photographer took all the progress photographs on the work of the North River Division, made photographic reductions of all drawings and plans, made lantern slides of all negatives of a more important nature, and, in addition, during the period of compressed air, analyzed the samples of compressed air, brought into the office for the purpose, for the amount of CO_2 present. About $8 000 was spent on this department.

(*E*).—*Despatch-Boat Service.*—To provide access to the New Jersey side, a despatch boat was purchased. This boat was at first (June, 1904) chartered, and in May, 1905, was bought outright, and ran on regular schedules, day and night. It continued in the service until

April, 1909, when it was given up, as the tunnels were so far completed that they provided easy access to New Jersey. The cost of the boat (second-hand) was about $3 000. It was then thoroughly overhauled and the cabin remodeled. The monthly cost, when working a 12-hour shift, was $270 for manning, $65 for supplies, and $64 for coal. On two 12-hour shifts, the monthly cost was $533 for manning, $100 for supplies, and $96 for coal. About 100 000 passengers were carried during the boat's period of service, and the total cost was about $37 500.

For the major part of the period embraced by this paper, B. H. M. Hewett, M. Am. Soc. C. E., served as General Resident Engineer, in charge of the Field Work as a whole.

W. L. Brown, M. Am. Soc. C. E., was at first Resident Engineer of the work constructed from the Manhattan Shaft, while H. F. D. Burke, M. Am. Soc. C. E., was Resident Engineer of the work constructed from the Weehawken Shaft. After the meeting of the shields, Mr. Burke left to take up another appointment, and from that time Mr. Brown acted as Resident Engineer.

It may be said, without reflecting in any way on the manufacturers, that the high standard of all the metal materials also testified to the efficient inspection conducted under the direction of Mr. J. C. Naegeley.

It is impossible to close this brief account of these tunnels without recording the invaluable services at all times rendered by the members of the Company's field staff. Where all worked with one common aim it might seem invidious to single out names, but special credit is due to the following Assistant Engineers: Messrs. H. E. Boardman, Assoc. M. Am. Soc. C. E., W. H. Lyon, H. U. Hitchcock, E. R. Peckens, H. J. Wild, Assoc. M. Am. Soc. C. E., J. F. Sullivan, Assoc. M. Am. Soc. C. E., and R. T. Robinson, Assoc. M. Am. Soc. C. E. Mr. C. E. Price was in charge of the cement tests throughout the entire period, and brought to his work not only ability but enthusiasm. Mr. H. D. Bastow was in charge of the photographic work, and Mr. A. L. Heyer of the cost account records, in which he was ably seconded by Mr. A. P. Gehling, who, after Mr. Heyer's departure, finished the records and brought them into their final shape. The organization of the Company's field engineering staff is shown graphically by Fig. 24.

FIELD ORGANIZATION OF THE O'ROURKE ENGINEERING CONSTRUCTION COMPANY FOR THE BUILDING OF THE PENNSYLVANIA RAILROAD TUNNELS INTO NEW YORK CITY—NORTH RIVER DIVISION. SECTIONS GY EAST, GY WEST SUPPLEMENTARY, GY WEST, AND GJ.

- GENERAL SUPERINTENDENT.
  - (General, Surface and Office)
    - ASSISTANT GENERAL SUPERINTENDENT.
      - FIELD OFFICE.
        - Civil Engineer.
        - Inspectors.
        - Book-keepers.
        - Paymaster.
        - Head Storekeeper.
        - Storekeepers.
        - Timekeepers.
        - Telephone Operators.
        - Office Boys.
        - Messengers.
        - Janitors.
      - SURFACE.
        - Head Carpenter.
        - Foreman Carpenter.
        - Carpenters.
        - Carpenters' Helpers.
        - Blacksmiths.
        - Blacksmiths' Helpers.
        - Foreman Laborers.
        - Laborers.
        - Disposal Trimmers.
        - Teamsters.
      - DESPATCH BOAT.
        - Captain.
        - Engineer.
        - Deck Hands.
  - (Excavation of Land Tunnels)
    - GENERAL ROCK SUPT.
      - Tunnel Supts.
      - Tunnel Foremen.
      - Foremen Timbermen.
      - Timbermen.
      - Timbermen's Helpers.
      - Foremen Drillers.
      - Drillers.
      - Foremen Muckers.
      - Pipe Fitters.
      - Pipe Fitters' Helpers.
      - Electricians.
      - Hoist Engineers.
      - Signalmen.
      - Muckers.
      - Nippers.
      - Water Boys.
  - (Shield Tunnel Driving)
    - GENERAL TUNNEL SUPERINTENDENT.
      - ASSISTANT SUPERINTENDENTS.
        - EXCAVATION.
          - General Foremen.
          - Foremen Drillers.
          - Drillers.
          - Powdermen.
          - Foremen Timbermen.
          - Timbermen.
          - Foremen Muckers.
          - Muckers.
          - Shieldmen.
          - Laborers.
          - Nippers.
          - Water Boys
        - IRON LINING.
          - Foremen.
          - Erector Runners.
          - Ironmen.
          - Boltmen.
        - CAULKING AND GRUMMETING.
          - Foremen.
          - Caulkers.
          - Grummeters.
        - GENERAL.
          - Pipefitters.
          - Pipefitters' Helpers.
          - Electricians.
          - Electricians' Helpers.
          - Trackmen.
          - Lockmen.
          - Transport Foreman.
          - Transport Laborers.
          - Watchmen.
  - (Masonry Lining-Rock and River Tunnels)
    - GENERAL CONCRETE SUPERINTENDENT.
      - TUNNEL SUPERINTENDENTS.
        - CONCRETE.
          - Foremen.
          - Carpenters.
          - Carpenters' Helpers.
          - Mixer Foremen.
          - Mixer Laborors.
          - Concrete Laborers.
        - BRICKWORK.
          - Foremen.
          - Bricklayers.
          - Bricklayers' Laborers.
          - Carpenters.
          - Carpenters' Helpers.
        - DUCTS.
          - Foremen.
          - Duct-layers.
        - WATER-PROOFING.
          - Foremen.
          - Waterproofers.
        - GENERAL.
          - Pipefitters.
          - Pipefitters' Helpers.
          - Electricians.
          - Electricians' Helpers.
          - Transport Foremen.
          - Transport Laborers.
          - Watchmen.
  - (Power Plant)
    - MASTER MECHANIC.
      - Foreman Electrician.
      - Electricians.
      - Engineers.
      - Foreman Machinist.
      - Machinists.
      - Machinists' Helpers.
      - Firemen.
      - Oilers.
      - Pumpmen.
      - Hoist Engineers.
      - Signalmen.
  - (Medical Supervision)
    - CHIEF MED. OFFICER.
      - Resident Doctor.

FIG. 24.

Contractor's Organization.—The contracting firm which did the work described in this paper was the O'Rourke Engineering Construction Company, of New York City. The President of this Company is John F. O'Rourke, M. Am. Soc. C. E., the Vice-President is F. J. Gubelman, Assoc. M. Am. Soc. C. E. The General Superintendent was Mr. George B. Fry, assisted by J. F. Sullivan, Assoc. M. Am. Soc. C. E. The duties of General Tunnel Superintendent fell to Mr. Patrick Fitzgerald. The generally pleasant relations existing between the Company and the contractor's forces did much to facilitate its execution.

The organization of the Contractor's field staff is shown on Fig. 25.

PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD COMPANY.
NORTH RIVER DIVISION.

SECTIONS GY EAST, GY WEST SUPPLEMENTARY, GY WEST, GJ, AND I, *i. e.*, FROM 10TH AVENUE, MANHATTAN, TO THE WEEHAWKEN SHAFT, FIELD ENGINEERING STAFF ORGANIZATION.

GENERAL RESIDENT ENGINEER.

(Material Testing)
Cement Inspector.
Asst. Cement Inspectors.

(Photography)
Photographer.

(Construction)

(Cost Records)
Recording Clerk.
Asst. Recording Clerks.

(Despatch Boat)
Captain.
Engineers.
Deckhands.
Messengers.

(Office)
Clerks.
Messengers.

RESIDENT ENGINEERS.
(Two during driving of Shield-driven Tunnels, and one subsequently.)

(Inspection)
Assistant Engineers.
Chief Tunnel Inspector.
Tunnel Inspectors.
Surface Inspectors.
Clerks.

(Alignment)
Assistant Engineers.
Chiefs of Parties.
Instrumentmen.
Rodmen.
Chainmen.
Laborers.

(Office)
Draftsmen.
Field Office Clerks.
Cement Warehouse men.
Janitors.

FIG. 25.

In conclusion, the writers cannot forego the pleasure of expressing their deep obligation to Samuel Rea, M. Am. Soc. C. E., as representing the Management of the Company, to the Chief Engineer, Charles M. Jacobs, M. Am. Soc. C. E., and to James Forgie, M. Am. Soc. C. E., Chief Assistant Engineer, for their permission to write this paper, and also to all the members of the field office staff for their great and unfailing assistance in its preparation.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

A CONCRETE WATER TOWER.

Discussion.*

By Messrs. Maurice C. Couchot, L. J. Mensch, and A. H. Markwart.

Maurice C. Couchot, M. Am. Soc. C. E. (by letter).—It appears to the writer that in the design of this structure two features are open to criticism. The first is that such a high structure was built of plain concrete without any reinforcement. Even if the computation of stresses did not show the necessity for steel reinforcement, some should have been embedded in the work. As a matter of fact, the writer believes that, with the present knowledge of the benefit of reinforced concrete, a structure such as this should not be built without it. This applies mainly to the tower below the tank. Mr. Couchot.

The second feature, which is still more important, refers to the insertion of a shell of smooth steel plate to take the stresses due to the hydrostatic pressure, and also to insure against leakage in the walls of the tank. The 6-in. shell of plain concrete outside the steel shell. and the 3-in. shell inside, do not work together, and are practically of no value as walls, but are simply outside and inside linings. Although the designer provided lugs to insure the adhesion of the concrete to the plate, such precaution, in the writer's opinion, will not prevent the separation of the concrete from the smooth steel plate, and, at some future time, the water will reach and corrode the steel. It would have been better to have reinforced the wall of the tank with rods, as is generally done. The full thickness would have been available, and less plastering would have been required. Furthermore, the adhesion of concrete to a smooth steel plate is of doubtful value, for, in reinforced concrete, it is not the adhesion which does the work, but the gripping of the steel by the concrete in the process of setting.

*This discussion (of the paper by A. Kempkey, Jr., Jun. Am. Soc. C. E., printed in *Proceedings* for February, 1910, and presented at the meeting of March 16th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

Mr. Mensch. L. J. MENSCH, M. AM. SOC. C. E. (by letter).—This water-tower is probably the sightliest structure of its kind in North America; still, it does not look like a water-tower, and, from an architectural point of view, the crown portion is faulty, because it makes the tank appear to be much less in depth than it really is.

The cost of this structure far exceeds that of similar tanks in the United States. The stand-pipe at Attleboro, 50 ft. in diameter and 100 ft. high, cost about $25 000. Several years ago the writer proposed to build an elevated tank, 60 ft. in diameter and 40 ft. deep, the bottom of which was to be 50 ft. above the ground, for $21 000.

Among other elevated tanks known to the writer is one having a capacity of 100 000 gal., the bottom being 60 ft. above the ground.* The total quantities of material required for this tank are given as 4 480 cu. ft. of concrete, 23 200 lb. of reinforcing steel, and 27 600 ft., B. M., of form lumber and staging. Calculating at the abnormally high unit prices of 40 cents per cu. ft. for concrete, 4 cents per lb. for steel, and $50 per 1 000 ft., B. M., for lumber, the cost of the concrete would be $1 792, the steel, $928, and the form lumber and staging, $1 380. Adding to this the cost of a spiral staircase, at the high figure of $7 per linear foot in height, the total cost of this structure would be $4 598. The factor of safety used in this structure was four, but some engineers who are not familiar with concrete construction may require a higher factor. By doubling the quantities of concrete and steel, which would mean a tensile stress in the steel of only 8 000 lb. per sq. in., and a compressive stress in the concrete of only 225 lb. per sq. in., the cost of the tank would be only $7 318, as compared with the $16 578 mentioned in the paper. This enormous discrepancy between a good design and an amateur design, and between day-labor work and contract work should be a lesson which consulting engineers and managers of large corporations, who prefer their own designs and day-labor work, should take to heart.

Mr. Markwart. A. H. MARKWART, ASSOC. M. AM. SOC. C. E. (by letter).—It is the writer's opinion that the steel tank enclosed within the concrete of the upper cylinder, to take up the hoop tension and presumably to provide a water-tight tower, will not fulfill this latter requirement. If a plastered surface on the dome-shaped bottom provided the necessary imperviousness, it would seem that plastered walls would have proved satisfactory.

Apparently, the sheet-metal tank is intended to exclude the possibility of exterior leakage, but it occurs to the writer that it will fail to be efficient in this particular, because, under pressure, the water will force itself under the steel tank and the dome thrust rings and out to the exterior of the tower just below the tank, thus showing that insurance against leakage is actually provided by the plastered interior

*"The Reinforced Concrete Pocket Book," p. 124.

surfaces and not by the sheet-metal tank, and, for this reason, ordinary deformed rod reinforcement, in the writer's opinion, would have proved cheaper and better, and more in line with other parts of the reinforcement. Mr. Markwart.

Mr. Kempkey states:

"Before filling, the inside of the tank was given a plaster coat, consisting of 1 part cement to 1¾ parts of fine sand. This proved to be insufficient to prevent leakage, the water seeping through the dome and appearing on the outside of the structure along the line of the bottom of the rings. Three more coats were then applied over the entire tank, and two additional ones over the dome and about 8 ft. up on the sides, and except for one or two small spots which show just a sign of moisture, the tank is perfectly tight."

This substantiates the writer's contention that water-tightness was actually obtained by a liberal use of cement plaster, which would also have been true had the reinforcement been rods.

As a further comment, it might be stated that a water-tight concrete for the tank could have been obtained by adding from 8 to 10% of hydrated lime to the 1 : 2 : 4 mixture. This seems advisable in all cases where a water-tight concrete is necessary. The interior plastering could then have been done as a further precaution.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

SOME MOOTED QUESTIONS IN REINFORCED CONCRETE DESIGN.

Discussion.*

By Messrs. Joseph Wright, S. Bent Russell, J. R. Worcester, L. J. Mensch, Walter W. Clifford, J. C. Meem, George H. Myers, Edwin Thacher, and C. A. P. Turner.

Mr. Wright. Joseph Wright, M. Am. Soc. C. E. (by letter).—If, as is expected, Mr. Godfrey's paper serves to attract attention to the glaring inconsistencies commonly practiced in reinforced concrete designs, and particularly to the careless detailing of such structures, he will have accomplished a valuable purpose, and will deserve the gratitude of the Profession.

No engineer would expect a steel bridge to stand up if the detailing were left to the judgment or convenience of the mechanics of the shop, yet in many reinforced concrete designs but little more thought is given to the connections and continuity of the steel than if it were an unimportant element of the structure. Such examples, as illustrated by the retaining wall in Fig. 2, are common, the reinforcing bars of the counterfort being simply hooked by a 4-in. U-bend around those of the floor and wall slabs, and penetrating the latter only from 8 to 12 in. The writer can cite an example which is still worse—that of a T-wall, 16 ft. high, in which the vertical reinforcement of the wall slab consisted of ¾-in. bars, spaced 6 in. apart. The wall slab was 8 in. thick at the top and only 10 in. at the bottom, yet the ¾-in. vertical bars penetrated the floor slab only 8 in., and were

* This discussion (of the paper by Edward Godfrey, M. Am. Soc. C. E., printed in *Proceedings* for February, 1910, and presented at the meeting of March 16th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

simply hooked around its lower horizontal bars by a 4-in. **U**-bend. Amazing as it may appear, this structure was designed by an engineer who is well versed in the theories of reinforced concrete design. These are only two examples from a long list which might be cited to illustrate the carelessness often exhibited by engineers in detailing reinforced concrete structures. Mr. Wright.

In reinforced concrete work the detailer has often felt the need of some simple and efficient means of attaching one bar to another, but in its absence, it is inexcusable that he should resort to such makeshifts as are commonly used. A simple **U**-hook on the end of a bar will develop only a small part of the strength of the bar, and, of course, should not be relied on where the depth of penetration is inadequate; and, because of the necessity of efficient anchorage of the reinforcing bars where one member of a structure unites with another, it is believed that in some instances economy might be subserved by the use of shop shapes and shop connections in steel, instead of the ordinary reinforcing bars. Such cases are comparatively few, however, for the material in common use is readily adapted to the design, in the ordinary engineering structure, and only requires that its limitations be observed, and that the designer be as conscientious and consistent in detailing as though he were designing in steel.

This paper deserves attention, and it is hoped that each point therein will receive full and free discussion, but its main purport is a plea for simplicity, consistency, and conservatism in design, with which the writer is heartily in accord.

S. Bent Russell, M. Am. Soc. C. E. (by letter).—The author has given expression in a forcible way to feelings possessed no doubt by many careful designers in the field in question. The paper will serve a useful purpose in making somewhat clearer the limitations of reinforced concrete, and may tend to bring about a more economical use of reinforcing material. Mr. Russell.

It is safe to say that in steel bridges, as they were designed in the beginning, weakness was to be found in the connections and details, rather than in the principal members. In the modern advanced practice of bridge design the details will be found to have some excess of strength over the principal members. It is probable that the design of reinforced concrete structures will take the same general course, and that progress will be made toward safety in minor details and economy in principal bars.

Many of the author's points appear to be well taken, especially the first, the third, and the eighth.

In regard to shear bars, if it is assumed that vertical or inclined bars add materially to the strength of short deep beams, it can only be explained by viewing the beam as a framed structure or truss in which

Mr. Russell. the compression members are of concrete and the tension members of steel. It is evident that, as generally built, the truss will be found to be weak in the connections, more particularly, in some cases, in the connections between the tension and compression members, as mentioned in the author's first point.

It appears to the writer that this fault may be aggravated in the case of beams with top reinforcement for compression; this is scarcely touched on by the author. In such a case the top and bottom chords are of steel, with a weakly connected web system which, in practice, is usually composed of stirrup rods looped around the principal bars and held in position by the concrete which they are supposed to strengthen.

While on this phase of the subject, it may be proper to call attention to the fact that the Progress Report of the Special Committee on Concrete and Reinforced Concrete* may well be criticised for its scant attention to the case of beams reinforced on the compression side. No limitations are specified for the guidance of the designer, but approval is given to loading the steel with its full share of top-chord stress.†

In certain systems of reinforcement now in use, such as the Kahn and Cummings systems, the need for connections between the web system and the chord member is met to some degree, as is generally known. On the other hand, however, these systems do not provide for such intensity of pressure on the concrete at the points of connection as must occur by the author's demonstration in his first point. The author's criticisms on some other points would also apply to such systems, and it is not necessary to state that one weak detail will limit the strength of the truss.

The author has only condemnation for the use of longitudinal rods in concrete columns (Point 15). It would seem that if the longitudinal bars are to carry a part of the load they must be supported laterally by the concrete, and, as before in the beam, it may be likened to a framed structure in which the web system is formed of concrete alone, or of a framework of poorly connected members, and the concrete and steel must give mutual support in a way not easy to analyze. It is scarcely surprising that the strength of such a structure is sometimes less than that shown by concrete alone.

In the Minneapolis tests, quoted by the author, there are certain points which should be noted, in fairness to columns reinforced longitudinally. Only four columns thus reinforced failed below the strength shown by concrete alone, and these were from 52 to 63 days old only, while the plain concrete was 98 days old. There was nothing to hold the rods in place in these four columns except the concrete and the circular hoops surrounding them. On the other hand, all the

* *Transactions*, Am. Soc. C. E., Vol. LXVI, p. 431.

† *Loc. cit.*, p. 448.

columns in which the hooping was hooked around the individual rods showed materially greater strength than the plain concrete, although perhaps one should be excepted, as it was 158 days old and showed a strength of only 2 250 lb. per sq. in., or 12% more than the plain concrete.* Mr. Russell.

In considering a column reinforced with longitudinal rods and hoops, it is proper to remark that the concrete not confined by the steel ought not to be counted as aiding the latter in any way, and that, consequently, the bond of the outside bars is greatly weakened.

In view of these considerations, it may be found economical to give the steel reinforcement of columns some stiffness of its own by sufficiently connected lateral bracing. The writer would suggest, further, that in beams where rods are used in compression a system of web members sufficiently connected should be provided, so that the strength of the combined structure would be determinate.

To sum up briefly, columns and short deep beams, especially when the latter are doubly reinforced, should be designed as framed structures, and web members should be provided with stronger connections than have been customary.

J. R. Worcester, M. Am. Soc. C. E. (by letter).—This paper is of value in calling attention to many of the bad practices to be found in reinforced concrete work, and also in that it gives an opportunity for discussing certain features of design, about which engineers do not agree. A free discussion of these features will tend to unify methods. Several of the author's indictments, however, hit at practices which were discarded long ago by most designers, and are not recommended by any good authorities; the implication that they are in general use is unwarranted. Mr. Worcester.

The first criticism, that of bending rods at a sharp angle, may be said to be of this nature. Drawings may be made without indicating the curve, but in practice metal is seldom bent to a sharp angle. It is undoubtedly true that in every instance a gradual curve is preferable.

The author's second point, that a suitable anchorage is not provided for bent-up rods at the ends of a beam, may also be said to be a practice which is not recommended or used in the best designs.

The third point, in reference to the counterforts of retaining walls, is certainly aimed at a very reprehensible practice which should not be countenanced by any engineer.

The fourth, fifth, and sixth items bring out the fact that undoubtedly there has been some confusion in the minds of designers and authors on the subject of shear in the steel. The author is wholly justified in criticising the use of the shearing stress in the steel ever being brought into play in reinforced concrete. Referring to the

* *Engineering News*, Dec. 3d, 1908.

Mr. Worcester. report of the Special Committee on Concrete and Reinforced Concrete, on this point, it seems as if it might have made the intention of the Committee somewhat clearer had the word, tensile, been inserted in connection with the stress in the shear reinforcing rods. In considering a beam of reinforced concrete in which the shearing stresses are really diagonal, there is compression in one case and tension in another; and, assuming that the metal must be inserted to resist the tensile portion of this stress, it is not essential that it should necessarily be wholly parallel to the tensile stress. Vertical tensile members can prevent the cracking of the beam by diagonal tension, just as in a Howe truss all the tensile stresses due to shear are taken in a vertical direction, while the compressive stresses are carried in the diagonal direction by the wooden struts. The author seems to overlook the fact, however, that the reinforced concrete beam differs from the Howe truss in that the concrete forms a multiple system of diagonal compression members. It is not necessary that a stirrup at one point should carry all the vertical tension, as this vertical tension is distributed by the concrete. There is no doubt about the necessity of providing a suitable anchorage for the vertical stirrups, and such is definitely required in the recommendations of the Special Committee.

The cracks which the author refers to as being necessary before the reinforcing material is brought into action, are just as likely to occur in the case of the bent-up rods with anchors at the end, advocated by him. While his method may be a safe one, there is also no question that a suitable arrangement of vertical reinforcement may be all that is necessary to make substantial construction.

With reference to the seventh point, namely, methods of calculating moments, it might be said that it is not generally considered good practice to reduce the positive moments at the center of a span to the amount allowable in a beam fully fixed at the end, and if provision is made for a negative moment over supports sufficient to develop the stresses involved in complete continuity, there is usually a considerable margin of safety, from the fact of the lack of possible fixedness of the beams at the supports. The criticism is evidently aimed at practice not to be recommended.

As to the eighth point, the necessary width of a beam in order to transfer, by horizontal shear, the stress delivered to the concrete from the rods, it might be well worth while for the author to take into consideration the fact that while the bonding stress is developed to its full extent near the ends of the beam, it very frequently happens that only a portion of the total number of rods are left at the bottom, the others having been bent upward. It may be that the width of a beam would not be sufficient to carry the maximum bonding stress on the total number of rods near its center, and yet it may have ample shearing strength on the horizontal planes. The customary method of

determining the width of the beams so that the maximum horizontal shearing stress will not be excessive, seems to be a more rational method than that suggested by Mr. Godfrey. Mr. Worcester

Referring to the tenth and fourteenth points, it would be interesting to know whether the author proportions his steel to take the remaining tension without regard to the elongation possible at the point where it is located, considering the neutral axis of the section under the combined stress. Take, for instance, a chimney: If the section is first considered to be homogeneous material which will carry tension and compression equally well, and the neutral axis is found under the combined stresses, the extreme tensile fiber stress on the concrete will generally be a matter of 100 or 200 lb. Evidently, if steel is inserted to replace the concrete in tension, the corresponding stress in the steel cannot be more than from 1 500 to 3 000 lb. per sq. in. If sufficient steel is provided to keep the unit stress down to the proper figure, there can be little criticism of the method, but if it is worked to, say, 16 000 lb. per sq. in., it is evident that the result will be a different position for the neutral axis, invalidating the calculation and resulting in a greater stress in compression on the concrete.

L. J. MENSCH, M. AM. SOC. C. E. (by letter).—Much of the poor practice in reinforced concrete design to which Mr. Godfrey calls attention is due, in the writer's opinion, to inexperience on the part of the designer. Mr. Mensch.

It is true, however, that men of high standing, who derided reinforced concrete only a few years ago, now pose as reinforced concrete experts, and probably the author has the mistakes of these men in mind.

The questions which he propounds were settled long ago by a great many tests, made in various countries, by reliable authorities, although the theoretical side is not as easily answered; but it must be borne in mind that the stresses involved are mostly secondary, and, even in steel construction, these are difficult of solution. The stresses in the web of a deep steel girder are not known, and the web is strengthened by a liberal number of stiffening angles, which no expert can figure out to a nicety. The ultimate strength of built-up steel columns is not known, frequently not even within 30%; still less is known of the strength of columns consisting of thin steel casings, or of the types used in the Quebec Bridge. It seems to be impossible to solve the problem theoretically for the simplest case, but had the designer of that bridge known of the tests made by Hodgkinson more than 40 years ago, that accident probably would not have happened.

Practice is always ahead of theory, and the writer claims that, with the great number of thoroughly reliable tests made in the last 20 years, the man who is really informed on this subject will not see any reason for questioning the points brought out by Mr. Godfrey.

Mr. Mensch. The author is right in condemning sharp bends in reinforcing rods. Experienced men would not think of using them, if only for the reason that such sharp bends are very expensive, and that there is great likelihood of breaking the rods, or at least weakening them. Such sharp bends invite cracks.

Neither is there any question in regard to the advantage of continuing the bent-up rods over the supports. The author is manifestly wrong in stating that the reinforcing rods can only receive their increments of stress when the concrete is in tension. Generally, the contrary happens. In the ordinary adhesion test, the block of concrete is held by the jaws of the machine and the rod is pulled out; the concrete is clearly in compression.

The underside of continuous beams is in compression near the supports, yet no one will say that steel rods cannot take any stress there. It is quite surprising to learn that there are engineers who still doubt the advisibility of using bent-up bars in reinforced concrete beams. Disregarding the very thorough tests made during the last 18 years in Europe, attention is called to the valuable tests on thirty beams made by J. J. Harding, M. Am. Soc. C. E., for the Chicago, Milwaukee and St. Paul Railroad.* All the beams were reinforced with about $\frac{3}{4}$% of steel. Those with only straight rods, whether they were plain or patented bars, gave an average shearing strength of 150 lb. per sq. in. Those which had one-third of the bars bent up gave an average shearing strength of 200 lb. per sq. in., and those which had nearly one-half of the rods bent up gave an average shearing strength of 225 lb. per sq. in. Where the bent bars were continued over the supports, higher ultimate values were obtained than where some of the rods were stopped off near the supports; but in every case bent-up bars showed a greater carrying capacity than straight rods. The writer knows also of a number of tests with rods fastened to anchor-plates at the end, but the tests showed that they had only a slight increase of strength over straight rods, and certainly made a poorer showing than bent-up bars. The use of such threaded bars would increase materially the cost of construction, as well as the time of erection.

The writer confesses that he never saw or heard of such poor practices as mentioned in the author's third point. On the other hand, the proposed design of counterforts in retaining walls would not only be very expensive and difficult to install, but would also be a decided step backward in mechanics. This proposition recalls the trusses used before the introduction of the Fink truss, in which the load from the upper chord was transmitted by separate members directly to the abutments, the inventor probably going on the principle that the shortest way is the

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* *Journal* of the Western Society of Engineers, 1905.

best. There are in the United States many hundreds of rectangular water tanks. Are these held by any such devices? And as they are not thus held, and inasmuch as there is no doubt that they must carry the stress when filled with water, it is clear that, as long as the rods from the sides are strong enough to carry the tension and are bent with a liberal radius into the front wall and extended far enough to form a good anchorage, the connection will not be broken. The same applies to retaining walls. It would take up too much time to prove that the counterfort acts really as a beam, although the forces acting on it are not as easily found as those in a common beam. Mr. Mensch.

The writer does not quite understand the author's reference to shear rods. Possibly he means the longitudinal reinforcement, which it seems is sometimes calculated to carry 10 000 lb. per sq. in. in shear. The writer never heard of such a practice.

In regard to stirrups, Mr. Godfrey seems to be in doubt. They certainly do not act as the rivets of a plate girder, nor as the vertical rods of a Howe truss. They are best compared with the dowel pins and bolts of a compound wooden beam. The writer has seen tests made on compound concrete beams separated by copper plates and connected only by stirrups, and the strength of the combination was nearly the same as that of beams made in one piece.

Stirrups do not add much to the strength of the beams where bent bars are used, but the majority of tests show a great increase of strength where only straight reinforcing bars are used. Stirrups are safeguards against poor concrete and poor workmanship, and form a good connection where concreting is interrupted through inclemency of weather or other causes. They absolutely prevent shrinkage cracks between the stem and the flange of T-beams, and the separation of the stem and slab in case of serious fires. For the latter reason, the writer condemns the use of simple U-bars, and arranges all his stirrups so that they extend from 6 to 12 in. into the slabs. Engineers are warned not to follow the author's advice with regard to the omission of stirrups, but to use plenty of them in their designs, or sooner or later they will thoroughly repent it.

In regard to bending moments in continuous beams, the writer wishes to call attention to the fact that at least 99% of all reinforced structures are calculated with a reduction of 25% of the bending moment in the center, which requires only 20% of the ordinary bending moment of a freely supported beam at the supports. There may be some engineers who calculate a reduction of 33%; there are still some ultra-confident men, of little experience, who compute a reduction of 50%; but, inasmuch as most designers calculate with a reduction of only 25%, too great a factor of safety does not result, nor have any failures been observed on that account.

Mr. Mensch.

In the case of slabs which are uniformly loaded by earth or water pressure, the bending moments are regularly taken as $\frac{w\,l^2}{24}$ in the center and $\frac{w\,l^2}{12}$ at the supports. The writer never observed any failure of continuous beams over the supports, although he has often noticed failures in the supporting columns directly under the beams, where these columns are light in comparison with the beams. Failure of slabs over the supports is common, and therefore the writer always places extra rods over the supports near the top surface.

The width of the beams which Mr. Godfrey derives from his simple rule, that is, the width equals the sum of the peripheries of the reinforcing rods, is not upheld by theory or practice. In the first place, this width would depend on the kind of rods used. If a beam is reinforced by three $\frac{7}{8}$-in. round bars, the width, according to his formula, would be 8.2 in. If the beam is reinforced by six $\frac{5}{8}$-in. bars which have the same sectional area as the three $\frac{7}{8}$-in. bars, then the width should be 12 in., which is ridiculous and does not correspond with tests, which would show rather a better behavior for the six bars than for the three larger bars in a beam of the same width.

It is surprising to learn that there are engineers who still advocate such a width of the stem of T-beams that the favorable influence of the slab may be dispensed with, although there were many who did this 10 or 12 years ago.

It certainly can be laid down as an axiom that the man who uses complicated formulas has never had much opportunity to design or build in reinforced concrete, as the design alone might be more expensive than the difference in cost between concrete and structural steel work.

The author attacks the application of the elastic theory to reinforced concrete arches. He evidently has not made very many designs in which he used the elastic theory, or he would have found that the abutments need be only from three to four times thicker than the crown of the arch (and, therefore, their moments of inertia from 27 to 64 times greater), when the deformation of the abutments becomes negligible in the elastic equations. Certainly, the elastic theory gives a better guess in regard to the location of the line of pressure than any guess made without its use. The elastic theory was fully proved for arches by the remarkable tests, made in 1897 by the Austrian Society of Engineers and Architects, on full-sized arches of 70-ft. span, and the observed deflections and lateral deformations agreed exactly with the figured deformation.

Tests on full-sized arches also showed that the deformations caused by temperature changes agree with the elastic theory, but are not as great for the whole mass of the arch as is commonly assumed. The

elastic theory enables one to calculate arches much more quickly than any graphical or guess method yet proposed. Mr. Mensch.

Hooped columns are a patented construction which no one has the right to use without license or instructions from M. Considère, who clearly states that his formulas are correct only for rich concrete and for proper percentages of helical and longitudinal reinforcement, which latter must have a small spacing, in order to prevent the deformation of the core between the hoops. With these limitations his formulas are correct.

Mr. Godfrey brings up some erratic column tests, and seems to have no confidence in reinforced concrete columns. The majority of column tests, however, show an increase of strength by longitudinal reinforcement. In good concrete the longitudinal reinforcement may not be very effective or very economical, but it safeguards the strength in poorly made concrete, and is absolutely necessary on account of the bending stresses set up in such columns, due to the monolithic character of reinforced concrete work.

Mr. Godfrey does not seem to be familiar with the tests made by good authorities on square slabs of reinforced concrete and of cast iron, which latter material is also deficient in tensile strength. These tests prove quite conclusively that the maximum bending moment per linear foot may be calculated by the formulas, $\frac{w\,l^2}{32}$ or $\frac{w\,l^2}{20}$, according to the degree of fixture of the slabs at the four sides. Inasmuch as fixed ends are rarely obtained in practice, the formula, $\frac{w\,l^2}{24}$ is generally adopted and the writer cannot see any reason to confuse the subject by the introduction of a new method of calculation.

Walter W. Clifford, Jun. Am. Soc. C. E. (by letter).—Some of Mr. Godfrey's criticisms of reinforced concrete practice do not seem to be well taken, and the writer begs to call attention to a few points which seem to be weak. In Fig. 1, the author objects to the use of diagonal bars for the reason that, if the diagonal reinforcement is stressed to the allowable limit, these bars bring the bearing on the concrete, at the point where the diagonal joins the longitudinal reinforcement, above a safe value. The concrete at the point of juncture must give, to some extent, and this would distribute the bearing over a considerable length of rod. In some forms of patented reinforcement an additional safeguard is furnished by making the diagonals of flat straps. The stress in the rods at this point, moreover, is not generally the maximum allowable stress, for considerable is taken out of the rod by adhesion between the point of maximum stress and that of juncture. Mr. Clifford.

Mr. Godfrey wishes to remedy this by replacing the diagonals by

Mr. Clifford.

rods curved to a radius of from twenty to thirty times their diameter. In common cases this radius will be about equal to the depth of the beam. Let this be assumed to be true. It cannot be assumed that these rods take any appreciable vertical shear until their slope is 30° from the horizontal, for before this the tension in the rod would be more than twice the shear which causes it. Therefore, these curved rods, assuming them to be of sufficient size to take, as a vertical component, the shear on any vertical plane between the point where it slopes 30° and its point of maximum slope, would need to be spaced at, approximately, one-half the depth of the beam. Straight rods of equivalent strength, at 45° with the axis of the beam, at this same spacing (which would be ample), would be 10% less in length.

Mr. Godfrey states:

"Of course a reinforcing rod in a concrete beam receives its stress by increments imparted by the grip of the concrete; but these increments can only be imparted where the tendency of the concrete is to stretch."

He then overlooks the fact that at the end of a beam, such as he has shown, the maximum tension is diagonal, and at the neutral axis, not at the bottom; and the rod is in the best position to resist failure on the plane, *AB*, if its end is sufficiently well anchored. That this rod should be anchored is, as he states, undoubtedly so, but his implied objection to a bent end, as opposed to a nut, seems to the writer to be unfounded. In some recent tests, rods bent at right angles, with a length of 5 diameters at the end and a concrete backing, developed a stress on a straight length of about 30 diameters equal to the bond stress and approximately equal to the elastic limit of the rod, which, for reinforcing purposes, is its ultimate stress.

Concerning the vertical stirrups to which Mr. Godfrey refers, there is no doubt that they strengthen beams against failure by diagonal tension or, as more commonly known, shear failures. That they are not effective in the beam as built is plain, for, if one considers a vertical plane between the stirrups, the concrete must resist the shear on this plane, unless dependence is placed on that in the longitudinal reinforcemnt. This, the author states, is often done, but the practice is unknown to the writer, who does not consider it of any value; certainly the stirrups cannot aid.

Suppose, however, that the diagonal tension is above the ultimate stress for the concrete, failure of the concrete will then occur on planes perpendicular to the line of maximum tension, approximately 45° at the end of the beam. If the stirrups are spaced close enough, however, and are of sufficient strength so that these planes of failure all cut enough steel to take as tension the vertical shear on the plane, then these cracks will be very minute and will be distributed, as is the

case in the center of the lower part of the beam. These stirrups will then take as tension the vertical shear on any plane, and hold the beam together, so that the friction on these planes will keep up the strength of the concrete in horizontal shear. The concrete at the end of a simple beam is better able to take horizontal shear than vertical, because the compression on a horizontal plane is greater than that on a vertical plane. This idea concerning the action of stirrups falls under the ban of Mr. Godfrey's statement, that any member which "cannot act until failure has started, is not a proper element of design," but this is not necessarily true. For example, Mr. Godfrey says "the steel in the tension side of the beam should be considered as taking all the tension." This is undoubtedly true, but it cannot take place until the concrete has failed in tension at this point. If used, vertical tension members should be considered as taking all the vertical shear, and as Mr. Godfrey states, they should certainly have their ends anchored so as to develop the strength for which they have been calculated. Mr. Clifford.

The writer considers diagonal reinforcement to be the best for shear, and it should be used, especially in all cases of "unit" reinforcement; but, in some cases, stirrups can and do answer in the manner suggested; and, for reasons of practical construction, are sometimes best with "loose rod" reinforcement.

J. C. Meem, M. Am. Soc. C. E. (by letter).—The writer believes that there are some very interesting points in the author's somewhat iconoclastic paper which are worthy of careful study, and, if it be shown that he is right in most of, or even in any of, his assumptions, a further expression of approval is due to him. Few engineers have the time to show fully, by a process of *reductio ad absurdum,* that all the author's points are, or are not, well considered or well founded, but the writer desires to say that he has read this paper carefully, and believes that its fundamental principles are well grounded. Further, he believes that intricate mathematical formulas have no place in practice. This is particularly true where these elaborate mathematical calculations are founded on assumptions which are never found in practice or experiment, and which, even in theory, are extremely doubtful, and certainly are not possible within those limits of safety wherein the engineer is compelled to work. Mr. Meem.

The writer disagrees with the author in one essential point, however, and that is in the wholesale indictment of special reinforcement, such as stirrups, shear rods, etc. In the ordinary way in which these rods are used, they have no practical value, and their theoretical value is found only when the structure is stressed beyond its safe limits; nevertheless, occasions may arise when they have a definite practical value, if properly designed and placed, and, therefore, they should not be discriminated against absolutely.

Mr. Meem. Quoting the author, that "destructive criticism is of no value unless it offers something in its place," and in connection with the author's tenth point, the writer offers the following formula which he has always used in conjunction with the design of reinforced concrete slabs and beams. It is based on the formula for rectangular wooden beams, and assumes that the beam is designed on the principle that concrete in tension is as strong as that in compression, with the understanding that sufficient steel shall be placed on the tension side to make this true, thus fixing the neutral axis, as the author suggests, in the middle of the depth, that is, $M = \frac{1}{6}\, b\, d^2\, S$, M, of course, being the bending moment, and b and d, the breadth and depth, in inches. S is usually taken at from 400 to 600 lb., according to the conditions. In order to obtain the steel necessary to give the proper tensile strength to correspond with the compression side, the compression and tension areas of the beam are equated, that is

$$\tfrac{1}{12}\, b\, d^2\, S = a \times \left(\frac{d}{2} - x_{11}\right) \times S_{11},$$

where

a = the area of steel per linear foot,
x_{11} = the distance from the center of the steel to the outer fiber, and
S_{11} = the strength of the steel in tension.

Then for a beam, 12 in. wide,

$$d^2\, S = a\, S_{11} \left(\frac{d}{2} - x_{11}\right),$$

or

$$a = \frac{d^2\, S}{S_{11}\left(\frac{d}{2} - x_{11}\right)}.$$

Carrying this to its conclusion, we have, for example, in a beam 12 in. deep and 12 in. wide,

$S = 500$,
$S_{11} = 15\,000$,
$x_{11} = 2\frac{1}{2}$ in.
$a = 1.37$ sq. in. per ft.

The writer has used this formula very extensively, in calculating new work and also in checking other designs built or to be built, and he believes its results are absolutely safe. There is the further fact to its credit, that its simplicity bars very largely the possibility of error from its use. He sees no reason to introduce further complications into such a formula, when actual tests will show results varying more widely than is shown by a comparison between this simple formula and many more complicated ones.

Mr. Myers. George H. Myers, Jun. Am. Soc. C. E. (by letter).—This paper brings out a number of interesting points, but that which strikes the

writer most forcibly is the tenth, in regard to elaborate theories and complicated formulas for beams and slabs. The author's stand for simplicity in this regard is well taken. A formula for the design of beams and slabs need not be long or complicated in any respect. It can easily be obtained from the well-known fact that the moment at any point divided by the distance between the center of compression and the center of tension at that point gives the tension (or compression) in the beam. Mr. Myers.

The writer would place the neutral axis from 0.42 to 0.45 of the effective depth of the beam from the compression side rather than at the center, as Mr. Godfrey suggests. This higher position of the neutral axis is the one more generally shown by tests of beams. It gives the formula $M = 0.86\ d\ As\ f$, or $M = 0.85\ d\ As\ f$, which the writer believes is more accurate than $M = \frac{5}{6}\ d\ As\ f$, or $0.83\frac{1}{3}\ d\ As\ f$, which would result if the neutral axis were taken at the center of the beam.

d = depth of the beam from the compression side to the center of the steel;

As = the area of the steel;

and f = the allowable stress per square inch in the steel.

The difference, however, is very slight, the results from the two formulas being proportional to the two factors, $83\frac{1}{3}$ and 85 or 86. This formula gives the area of steel required for the moment. The percentage of steel to be used can easily be obtained from the allowable stresses in the concrete and the steel, and the dimensions of the beam can be obtained in the simplest manner. This formula is used with great success by one of the largest firms manufacturing reinforcing materials and designing concrete structures. It is well-known to the Profession, and the reason for using any other method, involving the Greek alphabet and many assumptions, is unknown to the writer. The only thing to assume—if it can be called assuming when there are so many tests to locate it—is the position of the neutral axis. A slight difference in this assumption affects the resulting design very little, and is inappreciable, from a practical point of view. It can be safely said that the neutral axis is at, or a little above, the center of the beam.

Further, it would seem that the criticism to the effect that the initial stress in the concrete is neglected is devoid of weight. As far as the designer is concerned, the initial stress is allowed for. The values for the stresses used in design are obtained from tests on blocks of concrete which have gone through the process of setting. Whatever initial stress exists in concrete due to this process of setting exists also in these blocks when they are tested. The value of the breaking load on concrete given by any outside measuring device used in these tests,

Mr. Myers. is the value of that stress over and above this initial stress. It is this value with which we work. It would seem that, if the initial stress is neglected in arriving at a safe working load, it would be safe to neglect it in the formula for design.

Mr. Thacher. EDWIN THACHER, M. AM. SOC. C. E. (by letter).—The writer will discuss this paper under the several "points" mentioned by the author.

First Point.—At the point where the first rod is bent up, the stress in this rod runs out. The other rods are sufficient to take the horizontal stress, and the bent-up portion provides only for the vertical and diagonal shearing stresses in the concrete.

Second Point.—The remarks on the first point are also applicable to the second one. Rod 3 provides for the shear.

Third Point.—In a beam, the shear rods run through the compression parts of the concrete and have sufficient anchorage. In a counterfort, the inclined rods are sufficient to take the overturning stress. The horizontal rods support the front wall and provide for shrinkage. The vertical rods also provide for shrinkage, and assist the diagonal rods against overturning. The anchorage is sufficient in all cases, and the proposed method is no more effective.

Fourth Point.—In bridge pins, bending and bearing usually govern, but, in case a wide bar pulled on a pin between the supports close to the bar, as happens in bolsters and post-caps of combination bridges and in other locations, shear would govern. Shear rods in concrete-steel beams are proportioned to take the vertical and diagonal shearing stresses. If proportioned for less stress per square inch than is used in the bottom bars, this cannot be considered dangerous practice.

Fifth Point.—Vertical stirrups are designed to act like the vertical rods in a Howe truss. Special literature is not required on the subject; it is known that the method used gives good results, and that is sufficient.

Sixth Point.—The common method is not "to assume each shear member as taking the horizontal shear occurring in the space from member to member," but to take all the shear from the center of the beam up to the bar in question.

Cracks do not necessarily endanger the safety of a beam. Any device that will prevent the cracks from opening wide enough to destroy the beam, is logical. By numerous experiments, Mr. Thaddeus Hyatt found that nuts and washers at the ends of reinforcing bars were worse than useless, and added nothing to the strength of the beams.

Seventh Point.—Beams can be designed, supported at the ends, fully continuous, or continuous to a greater or less extent, as desired. The common practice is to design slabs to take a negative moment

over the supports equal to one-half the positive moment at the center, or to bend up the alternate rods. This is simple and good practice, for no beam can fail as long as a method is provided by which to take care of all the stresses without overstraining any part. Mr. Thacher.

Eighth Point.—Bars in the bottom of a reinforced concrete beam are often placed too close to one another. The rule of spacing the bars not less than three diameters apart, is believed to be good practice.

Ninth Point.—To disregard the theory of T-beams, and work by rule-of-thumb, can hardly be considered good engineering.

Tenth Point.—The author appears to consider theories for reinforced concrete beams and slabs as useless refinements, but as long as theory and experiment agree so wonderfully well, theories will undoubtedly continue to be used.

Eleventh Point.—Calculations for chimneys are somewhat complex, but are better and safer than rule-of-thumb methods.

Twelfth Point.—Deflection is not very important.

Thirteenth Point.—The conclusion of the Austrian Society of Engineers and Architects, after numerous experiments, was that the elastic theory of the arch is the only true theory. No arch designed by the elastic theory was ever known to fail, unless on account of insecure foundations, therefore engineers can continue to use it with confidence and safety.

Fourteenth Point.—Calculations for temperature stresses, as per theory, are undoubtedly correct for the variations in temperature assumed. Similar calculations can also be made for shrinkage stresses, if desired. This will give a much better idea of the stresses to be provided for, than no calculations at all.

Fifteenth Point.—Experiments show that slender longitudinal rods, poorly supported, and embedded in a concrete column, add little or nothing to its strength; but stiff steel angles, securely latticed together, and embedded in the concrete column, will greatly increase its strength, and this construction is considered the most desirable when the size of the column has to be reduced to a minimum.

Sixteenth Point.—The commonly accepted theory of slabs supported on four sides can be correctly applied to reinforced concrete slabs, as it is only a question of providing for certain moments in the slab. This theory shows that unless the slab is square, or nearly so, nothing is to be gained by such construction.

C. A. P. Turner, M. Am. Soc. C. E. (by letter).—Mr. Godfrey has expressed his opinion on many questions in regard to concrete construction, but he has adduced no clean-cut statement of fact or tests, in support of his views, which will give them any weight whatever with the practical matter-of-fact builder. Mr. Turner.

Mr. Turner.

The usual rules of criticism place the burden of proof on the critic. Mr. Godfrey states that if his personal opinions are in error, it should be easy to prove them to be so, and seems to expect that the busy practical constructor will take sufficient interest in them to spend the time to write a treatise on the subject in order to place him right in the matter.

The writer will confine his discussion to only a few points of the many on which he disagrees with Mr. Godfrey.

First, regarding stirrups: These may be placed in the beam so as to be of little practical value. They were so placed in the majority of the tests made at the University of Illinois. Such stirrups differ widely in value from those used by Hennibique and other first-class constructors.

Mr. Godfrey's idea is that the entire pull of the main reinforcing rod should be taken up apparently at the end. When one frequently sees slabs tested, in which the steel breaks at the center, with no end anchorage whatever for the rods, the soundness of Mr. Godfrey's position may be questioned.

Again, concrete is a material which shows to the best advantage as a monolith, and, as such, the simple beam seems to be decidedly out of date to the experienced constructor.

Mr. Godfrey appears to consider that the hooping and vertical reinforcement of columns is of little value. He, however, presents for consideration nothing but his opinion of the matter, which appears to be based on an almost total lack of familiarity with such construction.

The writer will state a few facts regarding work which he has executed. Among such work have been columns in a number of buildings, with an 18-in. core, and carrying more than 500 tons; also columns in one building, which carry something like 1 100 tons on a 27-in. core. In each case there is about $1\frac{1}{2}$ in. of concrete outside the core for a protective coating. The working stress on the core, if it takes the load, is approximately equal to the ultimate strength of the concrete in cubes, to say nothing of the strength of cylinders fifteen times their diameter in height. These values have been used with entire confidence after testing full-sized columns designed with the proper proportions of vertical steel and hooping, and are regarded by the writer as having at least double the factor of safety used in ordinary designs of structural steel.

An advantage which the designer in concrete has over his fellow-engineer in the structural steel line, lies in the fact that, with a given type of reinforcement, his members are similar in form, and when the work is executed with ordinary care, there is less doubt as to the distribution of stress through a concrete column, than there is with the ordinary structural steel column, since the core is solid and the conditions are similar in all cases.

Tests of five columns are submitted herewith. The columns varied little in size, but somewhat in the amount of hooping, with slight differences in the vertical steel. The difference between Columns 1 and 3 is nearly 50%, due principally to the increase in hooping, and to a small addition in the amount of vertical steel. As to the efficiency of hooping and vertical reinforcement, the question may be asked Mr. Godfrey, and those who share his views, whether a column without reinforcement can be cast, which will equal the strength of those, the tests of which are submitted. Mr. Turner.

Test No. 1.*

Marks on column—none.
Reinforcement—eight $1\frac{1}{8}$-in. round bars vertically.
Band spacing—9 in. vertically.
Hooped with seven 32-in. wire spirals about 2-in. raise.
Outside diameter of hoops—$14\frac{1}{2}$ in.
Total load at failure—1 360 000 lb.
Remarks.—Point of failure was about 22 in. from the top. Little indication of failure until ultimate load was reached.
Some slight breaking off of concrete near the top cap, due possibly to the cap not being well seated in the column itself.

Test No. 2.

Marks on column—Box 4.
Reinforcement—eight $1\frac{1}{8}$-in. round bars vertically.
Band spacing about 13 in. vertically.
Wire spiral about 3-in. pitch.
Point of failure about 18 in. from top.
Top of cast-iron cap cracked at four corners.
Ultimate load—1 260 000 lb.
Remarks.—Both caps apparently well seated, as was the case with all the subsequent tests.

Test No. 3.

Marks on column—4–B.
Reinforcement—eight $\frac{7}{8}$-in. round bars vertically.
Hoops—$1\frac{3}{4}$ in. x $\frac{3}{16}$ in. x 14 in. outside diameter.
Band spacing—13 in. vertically.
Ultimate load—900 000 lb.
Point of failure about 2 ft. from top.
Remarks.—Concrete, at failure, considerably disintegrated, probably due to continuance of movement of machine after failure.

Test No. 4.

Marks on column—Box 4.
Reinforcement—eight 1-in. round bars vertically.
Hoops spaced 8 in. vertically.
Wire spirals as on other columns.
Total load at failure—1 260 000 lb.
Remarks.—First indications of failure were nearest the bottom end of the column, but the total failure was, as in all other columns.

* Tests made for C. A. P. Turner, by Mason D. Pratt, M. Am. Soc. C. E.

Mr. Turner.

within 2 ft. of the top. Large cracks in the shell of the column extended from both ends to very near the middle. This was the most satisfactory showing of all the columns, as the failure was extended over nearly the full length of the column.

TEST NO. 5.

Marks on column—none.
Reinforcement—eight $\frac{7}{8}$-in. bars vertically.
Hoops spaced 10 in. vertically.
Outside diameter of hoops—$14\frac{1}{2}$ in.
Wire spiral as before.
Load at failure—1 100 000 lb.
Ultimate load—1 130 000 lb.

Remarks.—The main point of failure in this, as in all other columns, was within 2 ft. of the top, although this column showed some scaling off at the lower end.

In these tests it will be noted that the concrete outside of the hooped area seems to have had very little value in determining the ultimate strength; that, figuring the compression on the core area and deducting the probable value of the vertical steel, these columns exhibited from 5 000 to 7 000 lb. per sq. in. as the ultimate strength of the hooped area, not considering the vertical steel. Some of them run over 8 000 lb.

The concrete mixture was 1 part Alpena Portland cement, 1 part sand, $1\frac{1}{2}$ parts buckwheat gravel and $3\frac{1}{2}$ parts gravel ranging from $\frac{1}{4}$ to $\frac{3}{4}$ in. in size.

The columns were cast in the early part of December, and tested in April. The conditions under which they hardened were not particularly favorable, owing to the season of the year.

The bands used were $1\frac{3}{4}$ by $\frac{1}{4}$ in., except in the light column, where they were $1\frac{3}{4}$ by $\frac{3}{16}$ in.

In his remarks regarding the tests at Minneapolis, Minn., Mr. Godfrey has failed to note that these tests, faulty as they undoubtedly were, both in the execution of the work, and in the placing of the reinforcement, as well as in the character of the hooping used, were sufficient to satisfy the Department of Buildings that rational design took into consideration the amount of hooping and the amount of vertical steel, and on a basis not far from that which the writer considers reasonable practice.

Again, Mr. Godfrey seems to misunderstand the influence of Poisson's ratio in multiple-way reinforcement. If Mr. Godfrey's ideas are correct, it will be found that a slab supported on two sides, and reinforced with rods running directly from support to support, is stronger than a similar slab reinforced with similar rods crossing it diagonally in pairs. Tests of these two kinds of slabs show that those with the diagonal reinforcement develop much greater strength than those reinforced directly from support to support. Records of small test slabs of this kind will be found in the library of the Society.

Mr. Godfrey makes the good point that the accuracy of an elastic

theory must be determined by the elastic deportment of the construction under load, and it seems to the writer that if authors of textbooks would pay some attention to this question and show by calculation that the elastic deportment of slabs is in keeping with their method of figuring, the gross errors in the theoretical treatment of slabs in the majority of works on reinforced concrete would be remedied. Mr. Turner.

Although he makes the excellent point noted, Mr. Godfrey very inconsistently fails to do this in connection with his theory of slabs, otherwise he would have perceived the absurdity of any method of calculating a multiple-way reinforcement by endeavoring to separate the construction into elementary beam strips. This old-fashioned method was discarded by the practical constructor many years ago, because he was forced to guarantee deflections of actual construction under severe tests. Almost every building department contains some regulation limiting the deflection of concrete floors under test, and yet no commissioner of buildings seems to know anything about calculating deflections.

In the course of his practice the writer has been required to give surety bonds of from $50 000 to $100 000 at a time, to guarantee under test both the strength and the deflection of large slabs reinforced in multiple directions, and has been able to do so with accuracy by methods which are equivalent to considering Poisson's ratio, and which are given in his book on concrete steel construction.

Until the engineer pays more attention to checking his complicated theories with facts as determined by tests of actual construction, the view, now quite general among the workers in reinforced concrete regarding him will continue to grow stronger, and their respect for him correspondingly less, until such time as he demonstrates the applicability of his theories to ordinary every-day problems.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will be reproduced in the volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

ROBERT L. ENGLE, M. Am. Soc. C. E.*

DIED OCTOBER 16TH, 1909.

Robert L. Engle was born on December 5th, 1846. He was a product of the time when opportunities for technical training were few, so that his engineering education was gained largely by contact with actual work. He began his professional career after the Civil War, in which he served for two years in the One Hundred and Forty-eighth Indiana Volunteer Infantry.

The first construction work of any note on which Mr. Engle was engaged was the building of the Ohio and Mississippi Railroad, now a part of the Baltimore and Ohio System, extending from Cincinnati to St. Louis. Later, and up to 1878, he was connected with the construction of the Cincinnati Southern Railway, Cincinnati's municipally owned railway, as Division Engineer, at Ray Springs, Tenn. This work included several tunnels and other heavy work in the mountain territory.

After the completion of the Cincinnati Southern, Mr. Engle went West, and was engaged in the construction of the Santa Fé Railroad at Trinidad, Colo., in the capacity of Assistant Chief Engineer. Under his direction the Royal Gorge Hanging Bridge was built, and much other interesting work was carried out. Mr. Engle's forte was location, and in the mountainous regions of the West he found ample exercise for this faculty. From Trinidad he moved to Santa Fé, N. Mex. His name is borne by Engle, N. Mex., now a thriving Western town.

While still in the West, Mr. Engle was connected with the Mexican Central Railroad, at Chihuahua, Mexico, on construction work, and with the Denver and Rio Grande Railroad. It is thus seen that he played a part in much of the important pioneer railroad development of the mountain region of the West.

In 1885, Mr. Engle began work on the location and construction of the Chicago, Burlington, and Northern Railroad, now part of the Burlington System, being located at St. Paul, Minn., as Assistant Chief Engineer of that portion of the line north of La Crosse, Wis. Later, his jurisdiction included the whole line. During 1887 and a part of 1888, he had charge of the construction of the Illinois Valley and Northern Railroad, as Chief Engineer, at La Salle, Ill. In the latter part of 1888 he conducted surveys for coal branch lines connect-

* Memoir prepared by O. E. Selby, Jun. Am. Soc. C. E.

ing with the Chesapeake and Ohio Railway, in the mountains of West Virginia.

Beginning in September, 1889, Mr. Engle was Resident Engineer on the construction of the Louisville and Jeffersonville Bridge over the Ohio River. During his term of service the substructure, involving several deep pneumatic foundations, was built, and parts of the approaches were erected. During his stay at Louisville Mr. Engle was selected as Arbitrator in a matter of disputed classification between the company and the contractor for the Pike's Peak Rack Railroad, and effected a satisfactory settlement. Among other things his later service included location work on the Tennessee Central Railroad, in 1892; location and construction work for the Missouri, Kansas and Texas Railroad, in Arkansas; and construction work on the Tidewater Railroad, now the Virginian Railway, at Princeton, W. Va. At the time of his death he was employed as Engineer for the contracting firm of Carpenter and Boxley, at Johnson City, Tenn.

With the death of Robert L. Engle, the Profession loses one of those sturdy, self-made engineers, to whom the country is largely indebted for pushing railroad construction overland and through the West. In character, rugged like the mountains with which he was associated, he was still the gentlest of souls to those associated with him in subordinate capacities. The writer knew him as Chief and friend for many years, and cannot recall any departures from the lines of the highest dignity, rectitude, good habits, and good nature.

Mr. Engle was a Member of the Engineers' Club of Cincinnati from the time of its organization. He maintained his home in Cincinnati for twenty-one years, while his engagements kept him at various other places.

On February 20th, 1879, Mr. Engle married Miss Sallie McQueety, of Cincinnati, and is survived by her and their son and two daughters. His family and social relations were most happy, although his enforced absences from home kept him from much of the social contact which his qualities deserved.

Mr. Engle was elected a Member of the American Society of Civil Engineers on September 7th, 1881.

CHARLES HERBERT DEANS, Assoc. M. Am. Soc. C. E.*

Died March 7th, 1909.

Charles Herbert Deans was born in Chester, Delaware County, Pa., on November 30th, 1863, and died at his home in Phœnixville, Pa., on March 7th, 1909.

His father, Charles Woodbury Deans, was prominent in educational

* Memoir prepared by Emil Diebitsch and Edwin S. Jarrett, Members, Am. Soc. C. E.

work, and was active in the early organization and in the popularization of the Common School System of the State of Pennsylvania.

On his father's side Mr. Deans was descended from the Deans and Sterling families, who, immediately following the War of the Revolution, emigrated from Connecticut to Susquehanna and Wyoming Counties, Pennsylvania. His mother was Priscilla Lyons Williams, of Chester, Delaware County, Pa., who was descended from the Lyons family of New Jersey and the Williams and Pennell families of Pennsylvania.

From both his father and his mother Mr. Deans inherited a taste and aptitude for study. His youthful environment was among books and in an atmosphere which naturally encouraged the desire he early formed to fit himself for a professional life.

His education was begun in private schools, but later he attended the public schools, and was graduated from the High School at Phœnixville, Pa., in 1881. He spent the next four years in practical work, learning business methods, becoming an excellent and accurate accountant, and familiarizing himself, in the works of the Phœnix Iron Company, with mill and shop methods and practice, and the metallurgy of iron and steel.

In 1885, Mr. Deans entered Lehigh University, well prepared in his studies, with a mind ripe for the absorption of further knowledge, and a temperament for enjoying to the utmost the four years of University life before him. He was a good student, standing well up in the first quarter of his class. He was elected a member of Theta Delta Chi Fraternity, was one of the Editors and Assistant Business Manager of the college Annual in his Junior year, and Business Manager of the Engineering Journal in his Senior year. He was graduated in 1889 with the degree of C. E.

As a boy Mr. Deans was fond of games and all healthy outdoor sports. He was a lover of Nature and of animals, fond of fishing and hunting, and was never happier than when roaming the beautiful woods and mountains of his native State. With such tastes it was natural to find him, in his college days, a participator in, and an enthusiastic supporter of, athletic games.

Not only in athletics, but in all things pertaining to Lehigh University, Mr. Deans was a most loyal and enthusiastic son of his Alma Mater, both at college and after he had gone out into the world. He thoroughly appreciated the benefits derived from his technical training, and was so eager that others should share them, that early in his business career he advanced sufficient funds to two ambitious young men to carry them through Lehigh.

Immediately after graduation Mr. Deans entered the employ of Sooysmith and Company, the well-known foundation engineers and contractors. He rapidly advanced to positions of responsibility with

this company, and, in 1895, became its Vice-President and Chief Executive Officer. When, a year or two later, Charles Sooysmith, M. Am. Soc. C. E., retired from active business, Mr. Deans organized, from the Sooysmith and Company staff, the Engineering Contract Company, of which he became President. Pressure of business seriously undermining his health, he was forced to give up temporarily all work in 1900, and to spend the next two years in the mountains of Northern Pennsylvania. On regaining his health, he associated himself with the firm of John Monks and Son of New York City, and, at the time of his death, he was Second Vice-President of that company.

While under his executive charge, both Sooysmith and Company and the Engineering Contract Company, constructed a number of the most important bridge foundations in the United States, and the former firm first successfully introduced pneumatic work in the foundations of the modern high office buildings of New York City, notably the Manhattan Life, Washington Life, Standard Oil, and Empire Buildings on Lower Broadway. At the time of his death, Mr. Deans was in full charge of the building of the piers of the reconstructed Baltimore and Ohio bridge over the Susquehanna River, at Havre de Grace, Md.

In the early years of his connection with Sooysmith and Company, Mr. Deans was employed on work in the field, rising from subordinate positions to that of Superintendent in responsible charge of work. During this period he acquired an intimate and practical knowledge of foundation construction, and his subsequent career gave evidence of the value of this training. Being thus well-equipped, Mr. Deans soon became notable as a business engineer. His judgment on all substructure engineering problems was quick and keen, his thorough technical knowledge being supplemented by his penetrating practical sense. His business ability was of a high order, and his efficiency was largely increased by his industry and methodical habits. As a negotiator, he was in the first rank. His quick appreciation of the essentials in business transactions, his fertile resource in the most complicated financial dealings, his patience and persistence in the face of discouragement or delay, and his inflexible determination when once his decisions were reached, were qualities which placed him in the highest rank as a contracting engineer. To those with whom he came in close contact, Mr. Deans will always be remembered as exemplifying the ideal combination of technical training with business efficiency.

He lightened the seriousness of his business transactions with a quick sense of fun, a fondness for a good story, and an infectious good humor. His genuine interest in the work of his associates and his unfeigned delight in their success won him many friendships which lasted throughout his life and which now keep his memory warm in the hearts of those who were fortunate enough to know him intimately.

Strong of will, keen and clear-sighted in business transactions, loyal to his friends and to the interests entrusted to him, he was, above all, a genial, honorable, many-sided man, who loved his fellow men.

Mr. Deans leaves a mother, Mrs. Charles W. Deans, of Phœnixville, Pa., a brother, John Sterling Deans, M. Am. Soc. C. E., Chief Engineer of the Phœnix Bridge Company, and two sisters, Mrs. R. Barclay Calley, of Seattle, Wash., and Mrs. Elmer E. Keiser, of Tacony, Pa.

In 1893, Mr. Deans married Miss Helen Arnold of West Chester, Pa., who, with two sons, Charles Woodbury, aged 15, and Malcolm Arnold, aged 13, survives him.

Mr. Deans was elected a Junior of the American Society of Civil Engineers, on December 3d, 1890, and an Associate Member on May 6th, 1896.

WILLIAM MEIER, Assoc. M. Am. Soc. C. E.*

Died February 14th, 1910.

William Meier, the son of the Reverend Jacob L. and Mary Meier, was born in Muscatine, Iowa, on April 10th, 1878, the family moving to Chicago, Ill., in the same year.

Mr. Meier received his education in the public schools of Chicago and at the University of Illinois, from which he was graduated in 1901, with the degree of B. S. in Civil Engineering.

After his graduation, Mr. Meier was engaged with various firms, principally in bridge and structural work. For a time he was with William M. Hughes, M. Am. Soc. C. E., and in January, 1905, he entered the service of the Scherzer Rolling Lift Bridge Company, as Assistant in the Chicago office; and later was appointed Assistant Engineer and Eastern Representative, with headquarters in New York City. At the time of his death, Mr. Meier was employed in the Bridge Department of the Chicago and North Western Railway.

On February 14th, 1910, in diving from a spring-board, in the natatorium of the Young Men's Christian Association, he struck his head against the side or bottom of the tank. When his body was taken from the water, life was extinct, and all efforts at resuscitation were futile.

Mr. Meier took great interest in all that pertained to his profession.

He was elected an Associate Member of the American Society of Civil Engineers, on June 1st, 1909. He was also a Member of the Western Society of Engineers.

* Memoir prepared by William A. Theodorsen and E. James Fucik, Associate Members, Am. Soc. C. E.

William P. Morse T

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PROCEEDINGS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS

VOL. XXXVI—No. 5

May, 1910

Published at the House of the Society, 220 West Fifty-seventh Street, New York, the Fourth Wednesday of each Month, except June and July.

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PROCEEDINGS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS

(INSTITUTED 1852)

VOL. XXXVI—No. 5

MAY, 1910

Edited by the Secretary, under the direction of the Committee on Publications.

CONTENTS

NEW YORK 1910.

Vol. XXXVI. MAY, 1910. No. 5.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PROCEEDINGS

SOCIETY AFFAIRS

CONTENTS

MINUTES OF MEETINGS

OF THE SOCIETY

April 20th, 1910.—The meeting was called to order at 8.30 P. M.; James Owen, M. Am. Soc. C. E., in the chair; Chas. Warren Hunt, Secretary; and present, also, 101 members and 15 guests.

A paper by H. M. Wilson, M. Am. Soc. C. E., entitled "Federal Investigations of Mine Accidents, Structural Materials, and Fuels, at the United States Testing Station, Pittsburg, Pa.," was presented by the author and illustrated with lantern slides.

The paper was discussed by Messrs. Kenneth Allen, H. G. Stott, and the author.

Adjourned.

May 4th, 1910.—The meeting was called to order at 8.30 P. M.; Vice-President G. H. Pegram in the chair; Chas. Warren Hunt, Secretary; and present, also, 147 members and 24 guests.

The minutes of the meetings of March 16th and April 6th, 1910, were approved as printed in *Proceedings* for April, 1910.

A paper by J. L. Campbell, M. Am. Soc. C. E., entitled, "The Water Supply of the El Paso and Southwestern Railway, from Carrizozo to Santa Rosa, N. Mex.," was presented by the Secretary, who also read a discussion on the subject from G. E. P. Smith, Assoc. M. Am. Soc. C. E.

A paper by George C. Clarke, M. Am. Soc. C. E., entitled, "The New York Tunnel Extension of the Pennsylvania Railroad: The Site of the Terminal Station," was presented by the author and illustrated with lantern slides.

The Secretary announced the election of the following candidates by the Board of Direction on May 3d, 1910:

As Members.

Charles Meirs Denise, Chicago, Ill.
Guy Hamilton Derrick, Pulaski, Va.
Charles Lincoln Hammond, Lowell, Mass.
Joseph Wray Hunter, Jenkintown, Pa.
Hans Petter Rude Jacobsen, New York City.
Herbert Miller Knight, Baltimore, Md.
Walter Ashfield McFarland, Washington, D. C.
Asa Hall Morrill, Dorchester, Mass.
Walter Levi Morse, New York City.
Paul Cook Nugent, Syracuse, N. Y.
Samuel Moreau Purdy, Brooklyn, N. Y.
John Henry Rostock, New York City.
James Henry Sullivan, Boston, Mass.
Frederick Goodman Vent, Chicago, Ill.
Emery Lafayette Walker, Philadelphia, Pa.
Delos Cuyler Washburn, Aberdeen, S. Dak.

As Associate Members.

Lynne John Bevan, New York City.
Horace Arthur Cook, Phœnix, Ariz.
George John Couchot, San Francisco, Cal.
Francis Trenholm Crowe, Boise, Idaho.
Albert Moore Currier, Cleveland, Ohio.
George Warren Cutting, Jr., Waltham, Mass.
William Dewoody Dickinson, Little Rock, Ark.
Harry Isaiah Dygert, Berkeley, Cal.
Walter Lewis Fitzgerald, Philadelphia, Pa.
Neal Bryant Garver, Toledo, Ohio.
Herbert August Gehring, Albany, N. Y.
Willard Livermore Gorton, Richfield, Idaho.
Benjamin Feland Groat, Massena, N. Y.
George Henry Harris, Joliet, Ill.

Clarke Kennerley Harvey, Pittsburg, Pa.
Roger Brooke Irwin, Baltimore, Md.
Mark Henry Kanary, Des Moines, Iowa.
Joseph Burr Koon, Chicago, Ill.
Ralph Briggs Kyle, Stone Harbor, N. J.
Richard Mack Lawton, New York City.
Richard John Lockwood, New Iberia, La.
Arthur Ernest Morgan, Washington, D. C.
John Parsons Newton, Albany, N. Y.
William Isaac Nolen, St. Paul, Minn.
Lee Elmo Philbrook, Chicago, Ill.
Guy Wickliffe Rice, Lakeview, Ore.
Henry Jenness Saunders, Laramie, Wyo.
Karl Garthwaite Smith, Newark, N. J.
Herbert Earl Stansbury, French, N. Mex.
Thomas Johnson Strickler, Kansas City, Mo.
Albert Willard Walker, Orman, S. Dak.
Walter Ward, Boise, Idaho.
Joe Young Work, Denver, Colo.

As Juniors.

William Henry Dittoe, Columbus, Ohio.
Walter Louis Drager, Johnstown, Pa.
Raymond West Ferris, Columbus, Ohio.
Francis Bonner Forbes, New York City.
John Henry Glander, Jr., Bloomfield, N. J.
Benjamin Hartley Hewit, Electric, Mont.
Edward Philip Leonard, Brooklyn, N. Y.
Edward Lewis Lincoln, Belmont, Mass.
Thomas Clayton Mott, High Falls, N. Y.
Frank Snow Parrigin, Gainesville, Fla.
Glenn Vernon Rhodes, San Francisco, Cal.
George Blaney Taylor, New Britain, Conn.
Frank Johnson Trelease, Mercedes, Tex.
Leslie Clifford Whittemore, Poughkeepsie, N. Y.

The Secretary announced the transfer of the following candidates by the Board of Direction on May 3d, 1910:

From Associate Member to Member.

David Guy Anderson, Philadelphia, Pa.
Harry Outen Cole, Corozal, Canal Zone, Panama.
William Pierce Cowles, Minneapolis, Minn.
John Stephen Doyle, Baltimore, Md.
James Albert McDonough, Wheeling, W. Va.
Alfred Merritt Quick, Baltimore, Md.

From Associate to Member.

Almon Homer Fuller, Seattle, Wash.

From Junior to Associate Member.

Arthur Whittemore Bacon, New Britain, Conn.
Elmer Ellsworth Barnard, Lynchburg, Va.
Frederic Burroughs, Pittsburg, Pa.
Hubert Harry Hall, San Francisco, Cal.
William Alfred Lamb, Washington, D. C.
Frank Rahn Shunk Layng, Greenville, Pa.
James Robinson McClintock, New York City.
Daniel Bernard O'Brien, Syracuse, N. Y.
James Lafayette Parker, New York City.
Vicente Saucedo, Monterey, N. L., Mexico.
Wilbor Dickens Stanton, Las Cascadas, Canal Zone, Panama.

From Junior to Associate.

Theodore Belzner, New York City.

The Secretary announced the death of Earl Edwin Erdmann, elected Junior, July 1st, 1909; died March 29th, 1910.

Adjourned.

OF THE BOARD OF DIRECTION

(Abstract)

May 3d, 1910.—President Bensel in the chair; Chas. Warren Hunt, Secretary; and present, also, Messrs. Belknap, Brackett, Churchill, Kimball, Knap, Loomis, Loweth, Pegram, Roberts, Schneider, Stuart, Swensson, Thompson, and Wilkins.

Ballots for membership were canvassed, resulting in the election of 16 Members, 33 Associate Members, and 14 Juniors, and the transfer of 6 Associate Members to the grade of Member, 1 Associate to the grade of Member, 11 Juniors to the grade of Associate Member, and 1 Junior to the grade of Associate.

Applications were considered, and other routine business transacted.

Adjourned.

ANNOUNCEMENTS

The House of the Society is open from 9 A. M. to 10 P. M., every day, except Sundays, Fourth of July, Thanksgiving Day, and Christmas Day.

FUTURE MEETINGS

June 1st, 1910.—8.30 P. M.—Two papers will be presented for discussion at this meeting, as follows: "The New York Tunnel Extension of the Pennsylvania Railroad: Meadows Division and Harrison Transfer Yard," by E. B. Temple, M. Am. Soc. C. E.; and "The New York Tunnel Extension of the Pennsylvania Railroad: The North River Tunnels," by B. H. M. Hewett and W. L. Brown, Members, Am. Soc. C. E.

These papers were printed in *Proceedings* for April, 1910.

September 7th, 1910.—8.30 P. M.—At this meeting a paper entitled "Remedies for Landslides and Slips on the Kanawha and Michigan Railway," by R. P. Black, Assoc. M. Am. Soc. C. E., will be presented for discussion.

This paper is printed in this number of *Proceedings*.

ANNUAL CONVENTION

The Forty-second Annual Convention of the Society will be held at Chicago, Ill., from June 21st to June 24th, 1910, inclusive.

A circular giving full information in reference to the Convention was issued on May 18th, 1910.

SEARCHES IN THE LIBRARY

In January, 1902, the Secretary was authorized to make searches in the Library, upon request, and to charge therefor the actual cost to the Society for the extra work required. Since that time many searches have been made, and bibliographies and other information on special subjects furnished.

The resulting satisfaction, to the members, who have made use of the resources of the Society in this manner, has been expressed frequently, and leaves little doubt that, if it were generally known to the membership that such work would be undertaken, many would avail themselves of it.

The cost is trifling compared with the value of the time of an engineer who looks up such matters himself, and the work can be performed quite as well, and much more quickly, by persons familiar with the Library.

In asking that such work be undertaken, members should specify clearly the subject to be covered, and whether references to general books only are desired, or whether a complete bibliography, involving search through periodical literature, is desired.

In reference to this work, the Appendix* to the Annual Report of the Board of Direction for the year ending December 31st, 1906, contains a summary of all searches made to that date.

PAPERS AND DISCUSSIONS

Members and others who take part in the oral discussion of the papers presented are urged to revise their remarks promptly. Written communications from those who cannot attend the meetings should be sent in at the earliest possible date after the issue of a paper in *Proceedings*. The issue of volumes of *Transactions* is dependent on the closing of discussions, and the co-operation of the membership in this matter is essential to the regular issue of each quarterly volume.

All papers accepted by the Publication Committee are classified by the Committee with respect to their availability for discussion at meetings.

Papers which, from their general nature, appear to be of a character suitable for oral discussion, will be published as heretofore in *Proceedings*, and set down for presentation to a future meeting of the Society, and, on these, oral discussion, as well as written communications, will be solicited.

All papers which do not come under this heading, that is to say, those which, from their mathematical or technical nature, in the opinion of the Committee, are not adapted to oral discussion, will not be scheduled for presentation to any meeting. Such papers will be published in *Proceedings* in the same manner as those which are to be presented at meetings, but written discussions, only, will be requested for subsequent publication in *Proceedings* and with the paper in the volumes of *Transactions*.

SUBSCRIPTION PRICE TO THE PUBLICATIONS OF THE SOCIETY

The following subscription rates have been fixed by the Board of Direction for the publications of the Society:

Proceedings, ten Numbers per annum, $8. Price for single numbers, $1.

* *Proceedings*, Vol. XXXIII, p. 20 (January, 1907).

Transactions, four Volumes per annum, \$12. Price for single volumes, \$4.

On the above prices there is a discount of 25% to members who desire extra copies of any of these publications, to Libraries, and to Book-dealers.

There is also an additional charge per annum, to cover foreign postage, of 75 cents for *Proceedings* and \$1 for *Transactions,* or 8 cents and 25 cents, respectively, for single numbers.

A special subscription rate has been fixed by the Board for the *Proceedings* of the Society for the benefit of Students in Technical Schools. This rate is \$4.50 per annum, and is available to any *bona fide* student of any technical school.

LOCAL ASSOCIATIONS OF MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

San Francisco Association

The San Francisco Association of Members of the American Society of Civil Engineers holds regular bi-monthly meetings, with banquet, and weekly informal luncheons. The former are held at 6 P. M., at the Fairmont Hotel, on the third Friday of February, April, June, August, October, and November, and also on the third Wednesday of December, the latter being the Annual Meeting of the Association.

Informal luncheons are held at 12.15 P. M. every Wednesday, and the place of meeting may be ascertained by communicating with the Secretary of the Association, E. T. Thurston, Jr., Assoc. M. Am. Soc. C. E., 623 Wells Fargo Building.

The by-laws of the Association provide for the extension of hospitality to any members of the Society who may be temporarily in San Francisco, and any such member will be gladly welcomed as a guest of the Association at any of the above meetings, if he will notify the Secretary that he is in San Francisco.

Colorado Association

(Abstract of Minutes of Meeting)

April 9th, 1910.—The meeting was called to order at 8.45 P. M.; George G. Anderson, Vice-President, in the chair; Winfield Holbrook acting as Secretary; and present, also, 15 members and 7 guests.

The minutes of the March meeting were read and approved.

Discussion on "The Denver Water-Works Question" was opened by George T. Prince, M. Am. Soc. C. E., followed by Messrs. Comstock, Huston, Field, Ulrick, Jaycox, Armstrong, and Anderson.

Adjourned.

PRIVILEGES OF ENGINEERING SOCIETIES EXTENDED TO MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Members of the American Society of Civil Engineers will be welcomed by the following Engineering Societies, both to the use of their Reading Rooms and at all Meetings:

American Institute of Mining Engineers, 29 West Thirty-ninth Street, New York City.

Associação dos Engenheiros Civis Portuguezes, Lisbon, Portugal.

Australasian Institute of Mining Engineers, Melbourne, Victoria, Australia.

Boston Society of Civil Engineers, 715 Tremont Temple, Boston, Mass.

Brooklyn Engineers' Club, 117 Remsen Street, Brooklyn, N. Y.

Canadian Society of Civil Engineers, 413 Dorchester Street, West, Montreal, Que., Canada.

Civil Engineers' Society of St. Paul, St. Paul, Minn.

Cleveland Engineering Society, 718 Caxton Building, Cleveland, Ohio.

Cleveland Institute of Engineers, Middlesbrough, England.

Colorado Association of Members, Am. Soc. C. E., H. J. Burt, Secy., 235 Equitable Building, Denver, Colo.

Engineers' and Architects' Club of Louisville, Ky., 303 Norton Building, Fourth and Jefferson Streets, Louisville, Ky.

Engineers' Club of Baltimore, Baltimore, Md.

Engineers' Club of Minneapolis, 17 South Sixth Street, Minneapolis, Minn.

Engineers' Club of Philadelphia, 1317 Spruce Street, Philadelphia, Pa.

Engineers' Club of St. Louis, 3817 Olive Street, St. Louis, Mo.

Engineers' Club of Toronto, 96 King Street, West, Toronto, Ont., Canada.

Engineers' Society of Pennsylvania, 219 Market Street, Harrisburg, Pa.

Engineers' Society of Western Pennsylvania, 803 Fulton Building, Pittsburg, Pa.

Institute of Marine Engineers, 58 Romford Road, Stratford, London, E., England.

Institution of Engineers of the River Plate, Buenos Aires, Argentine Republic.

Institution of Naval Architects, 5 Adelphi Terrace, London W. C., England.

Junior Institution of Engineers, 39 Victoria Street, Westminster, S. W., London, England.

Koninklijk Instituut van Ingenieurs, The Hague, The Netherlands.

Louisiana Engineering Society, 321 Hibernia Bank Building, New Orleans, La.

Memphis Engineering Society, Memphis, Tenn.

Midland Institute of Mining, Civil and Mechanical Engineers, Sheffield, England.

Montana Society of Engineers, Butte, Montana.

North of England Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne, England.

Oesterreichischer Ingenieur- und Architekten-Verein, Eschenbachgasse 9, Vienna, Austria.

Pacific Northwest Society of Engineers, 803 Central Building, Seattle, Wash.

Rochester Engineering Society, Rochester, N. Y.

Sachsischer Ingenieur- und Architekten-Verein, Dresden, Germany.

Sociedad Colombiana de Ingenieros, Bogota, Colombia.

Societe des Ingenieurs Civils de France, 19 Rue Blanche, Paris, France.

Society of Engineers, 17 Victoria Street, Westminster, S. W., London, England.

Svenska Teknologforeningen, Brunkebergstorg 18, Stockholm, Sweden.

Tekniske Forening, Vestre Boulevard 18–1, Copenhagen, Denmark.

Western Society of Engineers, 1737 Monadnock Block, Chicago, Ill.

ACCESSIONS TO THE LIBRARY

(From April 12th to May 9th, 1910)

DONATIONS*

MODERN LOCATION OF STANDARD TURNOUTS.

A Manual of Practice. By C. M. Kurtz. Leather, 6½ x 4 in., illus., 7 + 51 pp. San Francisco, Bolte & Braden Co., Printers, 1910. $1.25. (Donated by the Author.)

A secondary title describes this book as a practical treatment of the various problems connected with track engineering. It is intended especially for the use of transitmen, engineers, and draftsmen in making economical and first-class locations of turnouts and their connecting curves. The preface states that it may be substituted for, or used as a supplement to, the chapters on Turnouts or Frogs and Switches to be found in railway engineering field books which do not include solutions of problems in the laying out of "Y" tracks using standard turnouts, or "line" problems involving a turnout. The author assumes a knowledge of geometry and trigonometry and a familiarity with common circular curve problems on the part of those who use the book. The Contents are: Modern Practice in Locating Standard Turnouts; Problems: Turnouts from Tangents; Problems: Turnouts from Curves; Problems: Symmetrical "Y" Tracks; The Traverse Method; Turnout Tables; Crossover Tables.

CONCRETE-STEEL CONSTRUCTION (DER EISENBETONBAU).

By Emil Mörsch. Authorized Translation from the Third (1908) German Edition, Revised and Enlarged, by E. P. Goodrich, M. Am. Soc. C. E. Cloth, 10 x 7 in., illus., 9 + 368 pp. New York, The Engineering News Publishing Company; London, Archibald Constable and Company, Ltd., 1910. $5.00.

In the publisher's preface, it is stated that this book contains probably the clearest exposition of European methods of reinforced concrete construction that has been published. Owing to its limited usefulness to American engineers, the present translation has been made. The greater part of the work is stated, in the author's preface, to relate to the practical reinforcement of T-beams, columns, and arches under various loads. It also treats of the theory of reinforced concrete, the properties of materials, the application of theory to results of tests, the uses of reinforced concrete, and the most important fields of its utilization. For convenience the subject-matter in the translation has been divided into parts and chapters, and wherever possible the wording on the illustrations has been translated into English. The metric system of measurements is used, but the figures are followed by their English equivalents. A table of metric and English equivalents has been included at the end of the book. The Contents are: Introduction; Part I, Theory of Reinforced Concrete; Part II, Applications of Reinforced Concrete; Appendix: Preliminary Recommendations for the Design, Construction, and Testing of Reinforced Concrete Structures; Recommendations Regarding Methods of Calculation to be Used in Testing Reinforced Concrete Structures; Regulations of the Royal Prussian Ministry of Public Works, for the Construction of Reinforced Concrete Building, May 24, 1907; Index.

TABLES AND DIAGRAMS FOR OBTAINING THE RESISTING MOMENTS OF ECCENTRIC RIVETED CONNECTIONS.

By E. A. Rexford. Boards, 10 x 8 in., illus., unpaged. New York, The Engineering News Publishing Company, 1909. $1.00.

In an explanation as to the application of these tables, it is stated that their purpose is to facilitate the operations of obtaining the resisting moments of eccentric riveted connections, and that they are intended especially for use in designing connections to columns where eccentric loads are involved.

THE PRINCIPLES AND PRACTICE OF IRON FOUNDING.

By E. L. Rhead. Cloth, 9 x 6 in., illus., 8 + 505 pp. Manchester, England, The Scientific Publishing Company. 7 shillings 6 pence net.

The author's aim has been, it is stated, to make this book useful to those employed in iron foundries, to pattern-makers, draftsmen, and engineers. The subject-matter consists of a series of articles issued in the public press from 1905 to

* Unless otherwise specified, books in this list have been donated by the publishers.

1908, and is based on a course of lectures given annually by the author at the Municipal School of Technology at Manchester. The reader's attention is called to the troubles encountered in practical work, their causes, how to avoid them, and the precautions necessary to obtain the best results. The Contents are: Iron and Steel in the Foundry; Testing Cast Iron; Moulding Materials in the Foundry; Sand-Mixing Appliances in the Foundry; Foundry Blackings and Partings; Moulding Tools and Appliances; Foundry Moulds and Their Production; Moulding Operations; Cores and Core Making; Loam Moulding; Plate and Machine Moulding; Chill Castings; Malleable Castings; Melting Iron for Foundry Purposes; Blast Supply; Air Furnaces; Useful Data; Index.

A HISTORY OF THE LOGARITHMIC SLIDE RULE

And Allied Instruments. By Florian Cajori. Cloth, $7\frac{3}{4}$ x $5\frac{1}{4}$ in., illus., 7 + 126 + 10 pp. New York, The Engineering News Publishing Company; London, Archibald Constable & Co., Ltd., 1909. $1.00.

To settle the question in regard to the actual inventor of the slide rule has been, it is stated, the author's aim. The history of the development of the slide rule and its extensive practical uses in England prior to 1800 are shown, together with its adaptation to almost every branch of the arts in which calculation is required, subsequent to that time. The subject-matter includes a list of slide rules and also a bibliography of the subject. The Contents are: The Invention of Logarithms and of the Logarithmic Line of Numbers; Gunter's Scale and the Slide Rule Often Confounded; Conflicting Statements on the Invention of the Slide Rule; Disentanglement of the Main Facts; Development During the Second Half of the Seventeenth Century; Development in England, Germany, and France During the Eighteenth Century; Development in England, Germany, Austria, and France During the Nineteenth Century (First Half); Development in the United States During the Nineteenth Century; Development During Recent Times; Slide Rules Designed and Used Since 1800; Bibliography of the Slide Rule; Index.

ELECTRIC POWER PLANTS.

A Description of a Number of Power Stations. Designed by Thomas Edward Murray. Cloth, $9\frac{1}{2}$ x $6\frac{1}{4}$ in., illus., 13 + 337 pp. New York, 1910. (Donated by the Author.)

The engineering details of certain modern electric lighting and power plants which represent the most advanced design and construction, are given in this book. The author, who designed the plants described and supervised their construction, has omitted all theoretical discussion of the subject, it is stated, and, in order to make the book of practical utility to the electrical engineer and power station builder, has confined himself to an exposition of facts and of data valuable for purposes of comparison. The Contents are: Waterside Stations, Nos. 1 and 2 (which exhibit the installation and operation of units of exceptional size and large output); Central Power Station of the Brooklyn Rapid Transit Co. (which represents a system of high-tension distribution with rotary converter substations); Williamsburg Power Station (which is a high-tension station, especially showing the application of horizontal steam turbines as prime movers); Central Station of the Citizens' Light and Power Co., Rochester, N. Y., and Washington Street Power Station of the Utica Gas and Electric Co. (which represent typical installations for light and power in small cities); Power Plant of the Helderberg Cement Co. (an industrial plant wherein exceptional local conditions had to be met); Chattanooga and Tennessee River Power Co. (which represents a recent application of water power to the production of electrical energy); Gold Street Station of the Kings County Electric Light and Power Co. (which is an example of the earlier engine-driven station rebuilt as a turbine-driven station); Substations; Index.

THE CORROSION AND PRESERVATION OF IRON AND STEEL.

By Allerton S. Cushman, Assoc. Am. Soc. C. E., and Henry A. Gardner. Cloth, $9\frac{1}{2}$ x $6\frac{1}{2}$ in., illus., 20 + 373 pp. New York and London, McGraw-Hill Book Company, 1910. $4.00.

To present as simply as possible the results of the more recent researches on the corrosion and preservation of iron and steel has been the aim of the authors of this book, and while a number of specific cases of corrosion are discussed, the subject has been treated in a general way. The book has been written, it is stated, mainly to elucidate the electrolytic theory of corrosion and to put into the hands of technologists a working theory. The chapter on the Theory of Solution contains an explanation of the fundamental electro-chemical principles, which it is hoped will be helpful to all who are interested in the rapid rusting and decay of iron. In regard to protective coatings for iron, the authors state that they have tried to present the latest developments of this phase of the subject in a

general way in order that each investigator may apply the principles to his own particular problem. The Chapter Headings are: Introduction; The Problem of Corrosion; Theory of Solution; Theory of Corrosion; Application of Electrolytic Theory; The Inhibition and Stimulation of Corrosion; The Technical Protection of Iron and Steel; Relation of Pigments to the Corrosion of Iron; Recent Field Tests on Protective Coatings for Iron and Steel; Paints for Various Purposes; The Testing and Design of Protective Paints; Properties of Pigments; The Properties of Paint Vehicles; Appendix A, Presenting a Discussion Before the American Institute of Mining Engineers on the Corrosion of Water Jackets of Copper Blast Furnaces; Appendix B, Bibliography; Index.

SULLA COSTRUZIONE DEI MURI DI APPRODO SU FONDO FANGOSO.

By C. Barberis. Paper, 12 x 9 in., illus., 106 pp. Roma, Tipografia Co-operativa Sociale, 1909. (Donated by the Author.)

This book treats of the construction of quay walls on soft or shifting ground, as in the ports of Brest, Bordeaux, Trieste, Kiddepur, etc. The author first describes the construction of the quay wall at Trieste from 1867 to 1884, and states that similar methods were adopted at first in his work in the military port at Spezia. However, after observations of the behavior of quay walls in shifting bottoms, the author has found a new system for surmounting the technical and economical difficulties encountered, and describes the wall devised. He also describes experiments made with reinforced concrete, in order to find the most durable and economical construction for other quay walls in the port of Spezia. The book is fully illustrated with plates and contains a bibliography of eight pages.

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Replanning Reading; An Industrial City of a Hundred Thousand. By John Nolen. Geo. H. Ellis Co., Printers, Boston, 1910.

American Society for Testing Materials: Proceedings of the Twelfth Annual Meeting, June 29th, July 3d, 1909. Vol. IX. American Society for Testing Materials, Philadelphia, 1909.

Fifth Report of the Commissioners Appointed to Inquire and Report What Methods of Treating and Disposing of Sewage (Including any Liquid from any Factory or Manufacturing Process) May Properly be Adopted; Methods of Treating and Disposing of Sewage; Appendix III, Memoranda Giving the Results of Observations (Mainly during 1902-5) On Various Processes of Sewage Treatment. By Dr. G. McGowan, Dr. A. C. Houston, Mr. C. C. Frye, and Mr. G. B. Kershaw. Wyman & Sons, London, 1909.

Mitteilungen über Forschungsarbeiten auf dem Gebiete des Ingenieurwesens insbesondere aus den Laboratorien der Technischen Hochschulen. Herausgegeben vom Verein Deutscher Ingenieure. Heft 80-82. Springer, Berlin, 1910.

Zentralblatt der Bauverwaltung. Herausgegeben im Ministerium der Öffentlichen Arbeiten. Jahrgang 29, 1909. Wilhelm Ernst & Sohn, Berlin.

Steel Mains for Gas Distribution. By Walter Hole. Some Notes on Modern Gas-Main Laying. By W. H. Y. Webber. Local Government Officer and Contractor, London, 1910.

Town Planning in Practice; An Introduction to the Art of Designing Cities and Suburbs. By Raymond Unwin. T. Fisher Unwin, London, 1909.

Town Planning, Past, Present and Possible. By H. Inigo Triggs. Methuen & Co., London, 1909.

SUMMARY OF ACCESSIONS

(From April 12th to May 9th, 1910)

Donations (including 11 duplicates)	108
By purchase	10
Total	118

MEMBERSHIP

ADDITIONS

(April 12th to May 10th, 1910)

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BINCKLEY, GEORGE SYDNEY. Cons. Engr., Vancouver Power Co., Ltd., Vancouver, B. C., Canada		April 5, 1910
CONNICK, HARRIS DE HAVEN. Chf. Asst. Engr., Dept. of Public Works, Care, City Engr., San Francisco, Cal.	Jun. Assoc. M. M.	Jan. 3, 1899 Feb. 4, 1903 Feb. 1, 1910
DEGEN, OTTO WILLIAM. 1718 St. Charles St., Alameda, Cal.		April 5, 1910
DERRICK, GUY HAMILTON. Box 592, Pulaski, Va.		May 3, 1910
DOYLE, JOHN STEPHEN. 2451 Maryland Ave., Baltimore, Md.	Assoc. M. M.	Nov. 7, 1906 May 3, 1910
FARNHAM, ROBERT, JR. Asst. Engr. of Constr., P. R. R. Co., Union Station, Washington, D. C.	Assoc. M. M.	July 9, 1906 April 5, 1910
HOLT, ARTHUR GRANT. Div. Engr., C., M. & P. S. Ry., St. Maries, Kootenai Co., Idaho		April 5, 1910
MCCONAGHY, ROBERT ALLEN. Care, Chinese Eng. & Min. Co., Chinwangtao, North China		Feb. 1, 1910
MCDONOUGH, JAMES ALBERT. Junior Engr., U. S. Engr. Office, P. O. Box 75, Wheeling, W. Va.	Assoc. M. M.	April 3, 1907 May 3, 1910
MCFARLAND, WALTER ASHFIELD. Supt., Water Dept., Dist. of Columbia, Washington, D. C.		May 3, 1910
MARTIN, JAMES WILLIAM. U. S. Indian Service, 522 Bumiller Bldg., Los Angeles, Cal.	Assoc. M. M.	Nov. 1, 1899 April 5, 1910
NUGENT, PAUL COOK. Prof. of Civ. Eng., Syracuse Univ., 417 University Pl., Syracuse, N. Y.		May 3, 1910
PILLSBURY, FRANKLIN CALHOUN. Div. Engr., Mass. Highway Comm., 126 Massachusetts Ave., Boston, Mass.		Aug. 31, 1909
PRITCHETT, CHARLES MARCELLUS. Chf. Div. Engr., Bureau of Public Works, Manila, Philippine Islands	Assoc. M. M.	Sept. 2, 1903 Jan. 4, 1910
PURDY, SAMUEL MOREAU. Chf. Engr., E. E. Smith Contr. Co., 189 Fourth Ave. (Res., 470 Third St.), Brooklyn, N. Y.		May 3, 1910

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SULLIVAN, JAMES HENRY. Deputy Supt. of Streets, in Chg. of Highway Div., Room 44, City Hall, Boston, Mass.		May 3, 1910
TRUMBULL, MORRIS KINNARD. Prin. Asst. Engr., Chic. & W. Indiana R. R. Co., Room 67, Dearborn Station, Chicago, Ill.		April 5, 1910
WEEDIN, KIRBY CALHOUN. Asst. Engr., C., M. & P. S. Ry. Co., Morrison, Ill.		April 5, 1910
WILLIAMS, JOHN NORMAN SPENCER. Supt., Kahului R. R. Co., Kahului, Maui, Hawaii		April 5, 1910
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BENHAM, WEBSTER LANCE. Civ. and Cons. Engr., 713 Campbell Bldg., Oklahoma City, Okla.		April 5, 1910
BEVAN,. LYNNE JOHN. Asst. Engr., Viele, Blackwell & Buck, 49 Wall St., Room 601, New York City		May 3, 1910
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FITZGERALD, WALTER LEWIS. Designing Engr. for Sellers & Rippey (Res., 1416 Rush St.), Philadelphia, Pa..		May 3, 1910
HANCOCK, HENRY SYDNEY, JR. City and Waterworks Engr., Ft. William, Ont., Canada............................	Jun. Assoc. M.	Oct. 6, 1903 April 5, 1910
HARRIS, GEORGE HENRY. Asst. Engr., Mich. Cent. R. R., 103 North Center St., Joliet, Ill..................		May 3, 1910
HARTING, OTTO FREDERICK. Prin. Asst. Engr., Terminal R. R. Assoc. of St. Louis, 3817 Russell Ave., St. Louis, Mo....................................		April 5, 1910
HARVEY, CLARKE KENNERLEY. Asst. to Harry J. Lewis, Engr., 602 Times Bldg., Pittsburg, Pa.............		May 3, 1910
HILL, JOHN J. Engr. for Stewart-Kerbaugh-Shanley Co., Contr. 12, New York State Barge Canal, Brewerton, N. Y..		April 5, 1910
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HUDSON, DARWIN SHAW. Asst. Supt. of Constr., The Astoria Light, Heat & Power Co., 157 Franklin St., Astoria, N. Y..............................		April 5, 1910
IRWIN, ROGER BROOKE. Rd. Engr. of Cecil County, Md., Elkton, Md....................................		May 3, 1910
JACOBSON, ALFRED LEON. Chf. Engr., Coignet & Co., 28 Villa Dupont, Paris, France......................		April 5, 1910
JENNINGS, JOHN EDWARD. 1469 Pacific St., Brooklyn, N. Y..		Nov. 30, 1909
JOHNSON, ROBERT CHAN. Div. Engr. and Technical Advisor to Pres., Hunan Yueh Han Ry. Co., Ltd., Changsha, Hunan Province, China.........................		Feb. 1, 1910
KANARY, MARK HENRY. Gen. Supt., Des Moines Bridge & Iron Co.; Address, 1073 Twenty-eighth St., Des Moines, Ia..................................		May 3, 1910
KYLE, RALPH BRIGGS. Executive Engr., South Jersey Realty Co., 915 Real Estate Trust Bldg., Philadelphia, Pa...		May 3, 1910
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NOLEN, WILLIAM ISAAC. Care, Herzog Iron Works, St. Paul, Minn.		May 3, 1910
PECK, ERMON MILAND. Engr., in Chg. Mech. Dept., Water Works of Hartford, 260 Edgewood St., Hartford, Conn.		April 5, 1910
PENDLEBURY, EDWARD. Asst. Engr., Public Service Comm., 150 Nassau St., New York City (Res., 26 Franklin Pl., Arlington, N. J.)	Jun. Assoc. M.	Oct. 2, 1906 April 5, 1910
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SCHREIBER, HERMAN VICTOR. Managing Engr., Sellers & Rippey, 1301 Stephen Girard Bldg., Philadelphia, Pa.		Mar. 1, 1910
SHEFFIELD, EDWARD NEWTON. Asst. Engr., N. Y., N. H. & H. R. R., Uxbridge, Mass.		April 5, 1910
SMITH, CHESTER ALEXANDER. 823 Scarritt Bldg., Kansas City, Mo.		April 5, 1910
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WILLIAMS, HAROLD S. City Engr., Caldwell, Idaho	Jun. Assoc. M.	Sept. 1, 1908 April 5, 1910

JUNIORS

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ELLIS, HERBERT CRAM. 61 Forest Ave. East, Detroit, Mich.	April 5, 1910
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HENRY, PHILIP WALTER. Cons. Engr., 25 Broad St., New York City.

HILL, ERNEST ROWLAND. Asst. to Chf. Engr. of Elec. Traction, P. T. & T. R. R. Co., Pennsylvania Station, 7th Ave. and 32d St., New York City.

HOCKE, JULIUS GEORGE. Secy. and Treas., General Contr. & Eng. Co., 29 Broadway, New York City (Res., 669 Ave. C, Bayonne, N. J.).

HOWE, GEORGE EDWARD. Care, Lyon & Greenleaf, Wauseon, Ohio.

HUSS, GEORGE MOREHOUSE. Reserve, Wis.

LAWRENCE, EDGAR HEISLER. Structural Engr., Nimmons & Fellows, Archts., 2007 Peoples Gas Bldg., Chicago, Ill.

LEA, SUMTER, JR. Room 530, Woodward Bldg., Birmingham, Ala.

LUCAS, EUGENE WILLETT VAN COURT. 129 East 19th St., New York City.

MACDONALD, CHARLES. 26 Exchange Pl., New York City.

MERRILL, GEORGE NATHAN. Civ. and Cons. Engr. (Merrill & Sears), 274 Main St., Springfield, Mass.

MILES, JOHN WILEY. Chf. Engr., F. C. Mexicano Pacifico, Hotel Salina Cruz, Salina Cruz, Mexico.

MINER, CHARLES AUGUSTINE. 530 Bond Bldg., Washington, D. C.

MOLITOR, FREDERIC. Cons. Engr., 2 Rector St., New York City.

MOSSCROP, ALFRED MITTON. Director, Dorman, Long & Co., Ltd., Middlesbrough, England (Res., 36 East Boulevard, Rochester, N. Y.).

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PAYNE, WILLIAM ARTHUR. Gen. Supt. of Constr., and Engr. with Charles T. Wills, Inc., 286 Fifth Ave., New York City.

PHELPS, WILLIAM COLLINS. 165 Broadway, Room 1026a, New York City.

POST, HENRY WILLIS. Cons. Structural Engr., 30 West 38th St., New York City.

PROUT, HENRY GOSLEE. First Vice-Pres. and Gen. Mgr., Union Switch & Signal Co., 30 Church St., New York City.

ROBERTSON, MARSHALL POPE. Member, State Board of Engrs. of La., 904 North Boulevard, Baton Rouge, La.

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DEATHS

FRIZELL, JOSEPH PALMER. Elected Member, January 3d, 1883; died May 4th, 1910.

JOHNSON, LUTHER ELMAN. Elected Junior, September 6th, 1904; date of death unknown.

SPROUL, ARCHIBALD ALEXANDER. Elected Member, May 1st, 1909; died April 26th, 1910.

Total Membership of the Society, May 10th, 1910,

5 463

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST

(April 5th to May 9th, 1910)

NOTE.—*This list is published for the purpose of placing before the members of the Society, the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles, references are given by the number prefixed to each journal in this list:

(1) *Journal*, Assoc. Eng. Soc., 31 Milk St., Boston, Mass., 30c.
(2) *Proceedings*, Engrs. Club of Phila., 1317 Spruce St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Engrs, Monadnock Blk., Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Canada.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(8) *Stevens Institute Indicator*, Stevens Inst., Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 25c.
(10) *Cassier's Magazine*, New York City 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 25c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c.
(14) *Engineering Record*, New York City, 12c.
(15) *Railway Age Gazette*, New York City, 15c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Electric Railway Journal*, New York City, 10c.
(18) *Railway and Engineering Review*, Chicago, Ill., 10c.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England, 25c.
(22) *Iron and Coal Trades Review*, London, England, 25c.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gas Light Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World*, New York City, 10c.
(28) *Journal*, New England Water-Works Assoc., Boston, Mass., $1.
(29) *Journal*, Royal Society of Arts, London, England, 15c.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales* de l'Assoc. des Ing. Sortis des Ecoles Spéciales de Gand, Brussels, Belgium.
(32) *Mémoires et Compte Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economiques des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(37) *Revue de Mécanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Proceedings*, Am. Inst. Elec. Engrs., New York City, 50c.
(43) *Annales des Pontes et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governors Island, New York Harbor, 50c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 8c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift*, Verein Deutscher Ingenieure, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Düsseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift*, Oesterreichischer Ingenieur und Architekten Verein, Vienna, Austria.
(54) *Transactions*, Am. Soc. C. E., New York City, $4.
(55) *Transactions*, Am. Soc. M. E., New York City, $10.

(56) *Transactions,* Am. Inst. Min. Engrs., New York City, $5.
(57) *Colliery Guardian,* London, England.
(58) *Proceedings,* Engrs.' Soc. W. Pa., 803 Fulton Bldg., Pittsburg, Pa., 50c.
(59) *Transactions,* Mining Inst. of Scotland, London and Newcastle-upon-Tyne, England.
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(63) *Minutes of Proceedings,* Inst. C. E., London, England.
(64) *Power,* New York City, 20c.
(65) *Official Proceedings,* New York Railroad Club, Brooklyn, N. Y., 15c.
(66) *Journal of Gas Lighting,* London, England, 15c.
(67) *Cement and Engineering News,* Chicago, Ill., 25c.
(68) *Mining Journal,* London, England.
(70) *Engineering Review,* New York City, 10c.
(71) *Journal,* Iron and Steel Inst., London, England.
(71*a*) *Carnegie Scholarship Memoirs,* Iron and Steel Inst., London, England.
(73) *Electrician,* London, England, 18c.
(74) *Transactions,* Inst. of Min. and Metal., London, England.
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(81) *Zeitschrift für Architektur und Ingenieurwesen,* Wiesbaden, Germany.
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(88) *Bulletin* of the International Ry. Congress Assoc., Brussels, Belgium.
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(90) *Transactions,* Inst. of Naval Archts., London, England.
(91) *Transactions,* Soc. Naval Archts. and Marine Engrs., New York City.
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(93) *Revue de Métallurgie,* Paris, France, 4 fr. 50.
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(99) *Proceedings,* Am. Soc. of Municipal Improvements, New York City, $1.
(100) *Professional Memoirs,* Corps of Engrs., U. S. A., Washington, D. C., $1.
(101) *Metal Worker,* New York City, 10c.

LIST OF ARTICLES

Bridges.

Standard Specifications for Structural Steel for Bridges.* (Amer. Soc. for Testing Materials.) (89) Vol. 9.
The Quebec Bridge.* Gebhard Willrich. (100) Apr.
Steel Railway and Highway Bridges of the Province of Alberta.* J. C. Chalmers, A. M. Can. Soc. C. E. (Abstract of paper read before the Edmonton Eng. Soc.) (96) Apr. 1.
A Concrete Girder Bridge with Curved Bottom Chord.* (14) Apr. 9.
Widening the Floor of a Double-Track Masonry Viaduct.* (13) Apr. 14.
Electrical Operation of Eight-Track Lift Bridge.* (27) Apr. 14.
The Protection of Masonry and Concrete Bridges by Waterproofing.* (96) Apr. 15.
An Analysis of Concrete Bridge Failures.* C. R. Young. (Paper read before the Can. Cement and Concrete Assoc.) (86) Apr. 13; (14) Apr. 16.
Cost of Abutment Masonry and Slope Paving for Highway Bridge Foundations, Illinois and Mississippi Canal. (86) Apr. 20.
A Five-Mile Trestle across Albemarle Sound, Norfolk & Southern Ry.* (13) Apr. 21.
A Steel Arch Bridge in the Province of Yun-Nan, French China.* (13) Apr. 21.
Cost of Highway Bridges. (96) Apr. 22.
Pneumatic Caisson Piers in Alaska.* (14) Apr. 23.
Building a Concrete Bridge from an Existing Structure.* (14) Apr. 23.
Synopsis of Paper upon Bridge Floors.* G. N. Eustace. (96) Apr. 29.

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*Illustrated.

Bridges—(Continued).

The Bear River Viaduct.* (14) Apr. 30.
A Three-Hinged Reinforced Concrete Arch Viaduct.* (14) Apr. 30.
The Superstructure of the McKinley Bridge at St. Louis.* H. M. Morse. (14) Apr. 30.
Substructure of Cantilever Bridge over the Ohio River at Beaver, Pa., Pittsburgh & Lake Erie R. R.* (13) May 5.
The Bailey Avenue Bridge, Buffalo.* (14) May 7.
Pont-Rails Tournant d'Hofstade à Manœuvre Hydro-Electrique par Basculement pour le Passage de la Ligne à Double Voie Schaerbeek-Muysen au-dessus du Canal Malines-Louvain ; Description, Conduite et Entretien.* Eug. François. (30) Apr.
Les Ponts Suspendus Fixes, Système Gisclard ; le Pont de la Cassagne (Pyrénées-Orientales).* G. Leinekugel Le Cocq. (33) Apr. 9.
Pont en Bois sur Cables du Tü Miniak (Indes Néerlandaises).* (33) Apr. 23.
Die Neue Weichselbrücke bei Marienwerder.* (49) Pt. 1-2, 1910.
Die Knickfestigkeit der Druckgurte offener Brücken.* H. Zimmermann. (49) Pt. 4-6, 1910.
Berechnung von sechsfach statisch unbestimmten Gewölben.* W. Schachenmeier. (81) Pt. 2.
Zur Stauberechnung bei Flussbrücken.* A. Hofmann. (51) Feb. 9.
Dreigelenkbogenbrücke in Eisenbeton über die Schöneberger Strasse in Gaarden.* J. Gaugusch. (78) Feb. 20.
Strassenbrücken in Eisenbeton.* Emil Morgenstern. (78) Apr. 5.

Electrical.

Central Station Economics. W. L. Abbott. (4) Feb.
Light and Artificial Illumination.* G. H. Stickney. (98) Mar.
Continuous Current Boosters and Balancers.* W. Arthur Ker. (77) Apr.
Metallic Filament Lamps: Their Possible Beneficial Effects on Supply Undertakings. G. Wilkinson. (77) Apr.
Electric Motors and their Applications.* Chas. A. Raymond. (98) Apr.
Telephones. L. E. Wilson. (77) Apr.
Recent Developments in the Transmission of Electrical Energy at High Tensions on Overhead Lines.* E. W. Marchant and E. A. Watson. (77) Apr.
Efficiency of Short-Spark Methods of Generating Electrical Oscillations.* W. H. Eccles and A. J. Makower. (77) Apr.
Some Quantitive Measurements in Connection with Radiotelegraphy.* J. A. Fleming. (77) Apr.
The Adaptation of the Test Wire to Telephony.* W. Lulofs. (73) Apr. 1.
First Cost of Plant and Cost of Generating and Distributing Electricity for Lighting, Edison Electric Illuminating Co. of Brooklyn. (86) Apr. 6.
An Equitable Sliding Scale for Rates of Electric Power.* J. B. Gordon, Assoc. M. Am. Soc. C. E. (13) Apr. 7.
The Laying of Vitrified Conduit.* Harry C. Spillman. (27) Apr. 7.
New Electric Supply Station at Dundee.* (73) Apr. 8 ; (26) Apr. 1.
Westinghouse Phase-Advancer.* (73) Apr. 8 ; (26) Apr. 15.
Hydroelectric Installation at Strangfjord, Norway.* (27) Apr. 14.
The Induction Coil.* Benj. F. Bailey. (27) Serial beginning Apr. 14.
The Uses of Elecricity at the Works of the Manchester Dyers, Ltd.* (26) Apr. 15.
Electric Individual Drive in Continental Textile Mills.* W. R. Rothenberg. (26) Serial beginning Apr. 15.
The Automatic Regulation of Alternators. M. Seidner. (Abstract from *Elektrotechnische Zeitschrift*). (73) Serial beginning Apr. 15.
An Experimental Catenary Line.* (Abstract from *Electric Railway Journal.*) (73) Apr. 15.
Reserve Power Station ; the Power Plant and System of the Syracuse Lighting Company.* M. G. Kennedy. (27) Apr. 21.
Enameled-Wire Windings.* Charles R. Underhill. (27) Apr. 21.
Transformers for Metallic Filament Lamps.* (12) Apr. 22.
Electrostatic Charging of Telegraph Wires by Locomotives. R. W. Weightman. (Abstract from *Post-Office Elec. Engrs.' Jour.*) (12) Apr. 22.
The Transmission System of the Idaho-Oregon Power Company.* (96) Apr. 22.
Dalmatian Hydroelectric Plants.* (64) Apr. 26.
Street Illumination, Photometric Tests of Street Lighting in Budapest.* Francis Jehl. (27) Apr. 28.
Irrigation Pumping, Rates Charged for Electric Service in Colorado. E. C. Reybold, Jr. (27) Apr. 28.
Underground Conduits.* Paul P. Witham. (27) Apr. 28.

*Illustrated.

Electrical—(Continued).

Telegraphy of Photographs, Wireless and by Wire.* T. Thorne Baker. (Abstract of paper read before the Royal Inst.) (73) Apr. 29.
Leakage Reactance.* J. Rezelman. (73) Apr. 29.
Disruptive Strength with Transient Voltages.* Joseph L. R. Hayden and Charles P. Steinmetz. (42) May.
Observation of Harmonics in Current and in Voltage Wave Shapes of Transformers.* John J. Frank. (42) May.
Parallel Operation of Three-Phase Generators with Their Neutrals Interconnected.* George I. Rhodes. (42) May.
Combination Ice and Lighting Plant.* (27) May 5.
Die selbsttätigen Spannungsregler für Gleichstrom- und für Wechselstrom-Kraftwerke.* J. Schmidt. (48) Serial beginning Apr. 16.
Versuche mit Isoliermitteln. (From *Zeit.* des Bayerischen Revisions-Vereines.) (48) Serial beginning Apr. 16.

Marine.

Marine Propulsion by Electric Motors.* Henry Alexander Mavor, M. Inst. C. E. (63) Vol. 179.
Standard Specifications for Structural Steel for Ships.* (Amer. Soc. for Testing Materials.) (89) Vol. 9.
Speed and its Attainment in Different Types of Ships. Herbert C. Sadler. (8) Jan.
The Stability of Submarines.* Bernard C. Laws, A. M. Inst. C. E. (10) Apr.
Marine Steam Turbines with the Melville and Macalpine Speed-Reducing Gear.* (13) Apr. 7.
Ship-Resistance: A Numerical Analysis of the Distribution of Effective Horse-Power.* T. H. Havelock. (Paper read before the Phil. Soc. Univ. of Durham.) (11) Apr. 8.
The South African Mail Steamer *Balmoral Castle.* (11) Serial beginning Apr. 8.
The Japanese Battleship *Satsuma.** (12) Apr. 15.
Gun-Boat for Macao.* (11) Apr. 15.
The Forges et Chantiers de la Mediterranée.* (11) Serial beginning Apr. 22.
Hydrographic Service Steamer for the Canadian Government.* (96) Apr. 22.
Patterns for a Sheet Metal Boat.* (101) Apr. 30.
15-Yard Dipper Dredge.* (95) May.
New Bucket Dredgers for the Kaiser Wilhelm Canal.* (95) May.
A Rock-Lifting Dredger.* (95) May.
An Electrically-Operated Suction Dredger.* William T. Donnelly. (95) May.
Mammoth Clay-Cutting Suction Reclamation Dredgers.* (95) May.
The Most Economical Type of Boat for Operation on Western Rivers with an 8-Ft. Channel Depth.* John M. Sweeney, M. Am. Soc. M. E. (13) May 5.
Le Role Economique du Navire de Commerce Moderne. P. de Rousiers. (32) Feb.
Considérations sur une Explosion survenue à Bord du Tankvoilier *Jules Henry.** M. Dibos. (32) Feb.
L'Etat Actuel de la Construction des Sous-Marins et Submersibles.* Laubeuf. (32) Feb.
Note sur le Calcul des Portes Roulantes d'Ecluses à un Seul Vantail.* A. de Cock. (30) Apr.
Fabrication des Plaques de Blindage par le Procédé "Krupp."* Ugo F. Gregoretti. (From *Revista Marittima.*) (93) Apr.
Die Hellinganlage des Stettiner Vulcan, Zweigniederlassung Hamburg, gebaut von Hein, Lehmann & Co. A.-G. in Düsseldorf-Oberbilk.* A. Cyran. (48) Serial beginning Mar. 5.
Felsenbohrschiff für die k. k. Seebehörde in Triest.* Carl Stromek. (48) Mar. 26.

Mechanical.

The Resistance to Rotation of Disks in Water at High Speeds.* Arnold Hartley Gibson, Assoc. M. Inst. C. E. and A. Ryan. (63) Vol. 179.
Some Experiments on a Diesel Engine.* William Ernest Fisher and Edmund Baddeley Wood. (63) Vol. 179.
The Permanent Mold and its Effect on Cast Iron.* E. A. Custer. (89) Vol. 9.
Standard Specifications for Foundry Pig Iron. (Amer. Soc. for Testing Materials.) (89) Vol. 9.
The Closing of Blowholes in Steel Ingots.* Henry M. Howe. (89) Vol. 9.
Cost of Power for Various Industries under Ordinary Conditions. Charles T. Main and F. M. Gumby. (Paper read before the Bost. Soc. of Civ. Engrs.) (1) Mar.

*Illustrated.

Mechanical—(Continued).

Methods of Handling Iron Ore during Transportation from Mine to Blast Furnace.* James E. Little. (98) Mar.

Belt Factors. William W. Bird. (From *Jour. Worcester Poly. Inst.*) (25) Apr.

Boiler Attachments and Funnel Draft. H. K. Spencer. (94) Apr.

Boiler Repairs by Electric and Autogenous Welding.* A. Scott Younger. (Abstract of paper read before the Inst. of Engrs. and Shipbuilders in Scotland.) (94) Apr.

Mechanical Stoking.* (76) Apr.

Engine Driving by Compressed Air.* Snowden B. Redfield. (64) Apr. 5.

West's New Power Stoker for Horizontal Retorts.* (66) Apr. 5.

Gas Combustion.* Walter Grafton. (Paper read before the Scottish Junior Gas Assoc.) (66) Apr. 5.

A Motor Wagon for Transporting Structural Material in City Streets.* (13) Apr. 7.

The Mitchell Cantilever Grain Elevator.* August F. Bock. (20) Apr. 7.

Industrial Motor Cars for Short Hauls.* (20) Apr. 7.

Ice-Making from Exhaust Steam, Plant of the Holdrege, Neb., Lighting Company which Makes Ice as a By-Product.* (27) Apr. 7.

The Construction of Aeroplanes.* (12) Serial beginning Apr. 8.

A Heat Diagram for Use in Turbine Design.* John Morrow. (Paper read before the North-East Coast Inst. of Engrs. and Shipbuilders.) (47) Apr. 8.

Further Data on the Worcester Retort House.* Dana D. Barnum. (Paper read before the New England Assoc. of Gas Engrs.) (24) Apr. 11; (83) Apr. 15.

A Giant Excavator.* (12) Apr. 15.

Another Suggestive Instance of the Economy of Steam Power. (96) Apr. 15.

The Use of Aërial Wire Rope Tramways.* Henry M. Payne. (16) Apr. 16.

The Monorail System in Modern Foundry Practice.* Albert W. Moyer. (Paper read before the Pittsburgh Foundrymen's Assoc.) (62) Apr. 18.

Management of Water Gas Generators.* John F. Wing. (Paper read before the New England Assoc. of Gas Engrs.) (24) Apr. 18.

Automatic Oiling Meters.* Thomas D. Miller. (Paper read before the Amer. Gas Inst.) (24) Apr. 18.

Dessau Settings of Eighteen Vertical Retorts.* R. Geipert. (Abstract of paper read before the Assoc. of Gas Engrs. of Saxony and Thuringia.) (66) Apr. 19.

Street Illumination, Photometric Tests of Street Lighting in Budapest.* Francis Jehl. (27) Apr. 28.

Some Practical Aspects of Radiation: Having Reference to the Uses of Illuminating Gas.* J. G. Clark. (Abstract of paper read before the Jun. Gas Assoc.) (66) Apr. 26.

The Elevator Installation of the Metropolitan Life Tower.* (46) Apr. 30.

New Turbine Station at Cincinnati.* (17) Apr. 30.

Application of Low-Pressure Turbines to Compressor Work.* J. W. Sheperdson. (9) May.

The Fuel-Briquetting Industry. Charles L. Wright. (9) May.

A Practical Study of Power Costs. William O. Webber. (9) May.

Motor Application to Machine Tools.* Charles Fair. (42) May.

The Development of Oil Gas in California.* E. C. Jones. (Paper read before the Amer. Gas Inst.) (24) May 2.

Artificial Systems of Refrigeration. C. P. Wood. (64) May 3.

A Continuous Billet Mill, Important Addition to the Cambria Steel Company's Plant.* (20) May 5.

A Large Sand and Gravel Washing Plant.* (14) May 7.

Choice of Power for Textile Mills. Charles T. Main. (Abstract of paper read before the National Assoc. of Cotton Mfrs.) (14) May 7.

Installation d'un Laboratoire d'Aérodynamique.* G. Eiffel. (32) Jan.

L'Equilibre Longitudinal et la Courbure des Surfaces Portantes des Aéroplanes.* René Arnoux. (32) Jan.

Note Succinte sur l'Organisation Technique & Industrielle de l'Usine du Creusot; Visite du Bureau et du Comité de la Société des Ingénieurs Civils de France.* (32) Feb.

Ramoneur à Air Chaud, *le Dalmar.** (92) Mar.

Le Renouvellement de la Concession des Omnibus et des Tramways Municipaux à Paris.* (33) Apr. 2.

Projecteur Electrique Automobile de l'Armée française.* Ch. Dantin. (33) Apr. 16.

L'Evolution des Fours à Gaz d'Eclairage.* A. Grebel. (33) Serial beginning Apr. 23.

Die Autogene Schweissung.* H. Rinne. (50) Nov. 17.

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*Illustrated.

Mechanical (Continued).

Einige Bemerkungen über das Martinverfahren mit flüssigem Roheisen. W. Schdanow. (50) Serial beginning Dec. 8.
Ueber das Schweissen des Gusseisens.* E. Lamberton. (50) Dec. 29.
Die Formgebung der Schrägwalzen bei Richtmaschinen für Rohre und Rundstäbe.* F. Mayer. (50) Jan. 19.
Messung von Gasgeschwindigkeiten und Gasmengen.* A. Dosch. (50) Jan. 19.
Ueber Kugellager.* August Bauschlicher. (50) Serial beginning Jan. 26.
Maschinelle Herstellung von Formen für stehend zu giessende Rohre.* R. Ardelt. (50) Serial beginning Feb. 2.
Berechnungs-Tabelle für Zentrifugal-Pumpen und Reaktions-Turbinen.* Alfred Barbezat. (From *Schweiz. Bauztg.*) (97) Feb. 5.
Konstruktive Einzelheiten an doppeltwirkenden Viertaktgasmachinen.* R. Drawe. (50) Serial beginning Feb. 9; (48) Feb. 12.
Versuche mit selbstaufzeichnenden Dampfmessern.* K. Rummel. (48) Serial beginning Feb. 12; (50) Feb. 16.
Verluste in den Schaufeln von Freistrahldampfturbinen.* Nikolai Briling. (48) Serial beginning Feb. 12.
Elektrischer Einzelantrieb von Webstühlen. A. Milodrowski. (52) Jan. 31.
Streifzüge durch die Technik der Ziegelindustrie.* (80) Feb. 17.
Die Gesteinbohrmaschinen und ihre neuere Entwicklung.* Fr. Herbst. (48) Serial beginning Feb. 19.
Die Berechnung der Scheibenkolben.* C. Pfleiderer. (48) Feb. 19.
Die Dampfturbine Bauart Barbezat.* P. André. (97) Serial beginning Feb. 20.
Einige Gesichtspunkte für die Konstruktion der Thomasbirne.* W. G. Gillhausen. (50) Feb. 23.
Die Verladung von Massengütern im Eisenbahnbetrieb.* Schwabe. (48) Feb. 26.
Die Luftmenge und ihre Bedeutung für den Bau und Betrieb der Kupolöfen.* Georg Buzek. (50) Serial beginning Mar. 2.
Betriebskosten einer Gas- und einer aus Kolbenmaschinen und Dampf-turbinen gemischten Dampfkraftanlage.* W. Heym. (97) Mar. 5.
Das Breiten beim Walzen. Ernst M. Scheld. (50) Mar. 9.
Massenförderanlagen im lothringisch-luxemburgischen Minettegebiet, inbesondere die Seilförderungen des Eisenhütten-Aktien-Vereines Düdelingen.* Fr. Tillmann. (48) Mar. 12.
Die Gasreinigungsanlage der Bethlen-Falvahütte in Schwientochlowitz O.-S. Fr. Berger. (50) Mar. 16.
Das Sport-Luftschiff *Parseval V.* Alb. Simon. (48) Mar. 19.
Untersuchung von Automobilkühlern.* Walther. (48) Serial beginning Mar. 19.
Der Einfluss des Kesselsteines auf Wirtschaftlichkeit und Betriebsicherheit von Heizvorrichtungen.* E. Reutlinger. (48) Serial beginning Apr. 2.
Uber die Regulierung von Kreiselpumpen und- gebläsen.* H. Hoffmann. (97) Serial beginning Apr. 5.
Der mechanische Massentransport in der Giesserei.* Hubert Hermanns. (50) Serial beginning Apr. 6.
Neuere Gebläsemachinen mit selbsttätigen Plattenventilen.* Schwanecke. (50) Apr. 13.
Systematische Untersuchung und Berechnung der Bandbremsen.* H. Al. Siebeck. (48) Apr. 16.
Der allseitig geschlossene Hohlziegel (System Balg).* (80) Apr. 19.
Die Gutehoffnungshütte-Dampfturbine.* Banner. (97) Serial beginning Apr. 20.
Zur Theorie der Zentrifugalpumpen.* J. Bartl. (97) Serial beginning Apr. 20.
Die Kohlen- und Kokstransportanlage des Gaswerkes der Stadt München in Moosach.* H. Hermanns. (48) Apr. 23.

Metallurgical.

Some Remarks upon the Critical Points of Steel, their Method of Determination and the Value of Same.* George W. Sargent. (3) Apr.
Notes on Metal Losses in Copper Slags.* C. A. Grabill. (16) Apr. 9.
Charging and Cleaning Machines for Zinc Furnaces.* O. Saeger. (16) Apr. 9.
Treatment of Complex Zinc Sulphide Ores at Oker. Hermann Pape. (16) Apr. 16.
Theoretical Notes on Reverberatory Furnaces. C. A. Grabill. (16) Apr. 16.
High Speed Steel and its Heat Treatment. W. G. Smith. (From *Armour Engr.*) (13) Apr. 21.
The New International Smeltery at Tooele, Utah.* John Tyssowski. (16) Apr. 23.
Cyaniding Silver Ores in Mexico.* E. Girault. (45) May.
Handling Tailings at Colorado City.* R. L. Herrick. (45) May.
Fabrication des Plaques de Blindage par le Procédé "Krupp."* Ugo F. Gregoretti. (From *Revista Marittima.*) (93) Apr.
Die Roheisenerzeugung im elektrischen Hochofen in Domnarfvet (Schweden).* B. Neumann. (50) Nov. 17.

*Illustrated.

Metallurgical—(Continued).

Zum heutigen Stande des Herdfrischverfahren.* Otto Petersen. (Paper read before the Vereins deutscher Eisenhüttenleute.) (50) Serial beginning Jan. 5.
Experimentelle Untersuchungen des Hoeschverfahrens.* Fr. Springorum. (50) Mar. 9.
Die neue Hochofenanlage der Gutehoffnungshütte.* Fr. Frölich. (50) Mar. 16.
Berechnung der Windmenge für Hochöfen. (50) Mar. 23.
Ueber Verwendung von Titan-Legierungen in der Stahlindustrie.* Wilhelm Venator. (50) Apr. 20.

Military.

Our Seacoast Defenses.* H. E. Cloke. (46) Apr. 9.

Mining.

The Ignition of Coal Dust by Single Electric Flashes.* W. M. Thornton and E. Bowden. (Abstract of paper read before North of England Inst. of Min. and Mech. Engrs.) (22) Apr. 8.
Electrical Colliery Installation in Scotland.* J. B. Van Brussel. (16) Apr. 9.
Method of Handling Slimes and Tailings.* A. O. Ihlseng. (16) Apr. 9.
Electricity at the Shamrock I. and II. Colliery, Herne, Westphalia, Germany.* H. M. Hudspeth. (Abstract of paper read before the North of England Inst. of Min. and Mech. Engrs.) (22) Apr. 15.
The Electrification of Murton Colliery, County Durham. E. Seymour. (Abstract of paper read before the North of England Inst. of Min. and Mech. Engrs.) (22) Apr. 15.
Recovery of a Large Fire-Sealed Area of a Coal Mine through Investigation with Oxygen Helmets. R. Y. Williams. (Abstract from *The Mining World.*) (13) Apr. 21.
New Plant at Birchenwood Collieries, Kidsgrove.* (22) Apr. 22.
Plant of the Dominion Asbestos Fibre Co.* (96) Apr. 22.
The North Pole Mine, Baker County, Oregon.* Emil Melzer. (16) Apr. 23.
Sinking by Means of Underhanging Tubbing.* (16) Apr. 23.
Cost of Churn Drilling. W. G. Weber. (Abstract from *Wisconsin Engr.*) (14) Apr. 23.
Oil Flotation Process at Broken Hill, N. S. W.* Theodore J. Hoover. (16) Apr. 30.
Surface Plant at Modern Coal Mine.* Warren R. Roberts. (45) May.
Moisture in Mine Air. (45) May.
Clay Screens *vs.* Drying Ores.* H. W. Fox. (45) May.
Tests of an Ilgner Electric Hoist.* R. R. Seeber. (42) May.
Brier Hill Concrete Lined Shaft, Vulcan, Mich.* William Kelly. (16) May 7.
A Novel System of Signaling.* Alfred Gradenwitz. (16) May 7.
Der Eisenbeton zum Auskleiden von Schächten im Steinkohlengebirge. Meurer. (51) Serial beginning Sup. No. 8.

Miscellaneous.

The Law of Conservation of Energy.* Charles P. Steinmetz. (4) Feb.
Random Notes on Engineering in the Philippine Islands. Amos A. Fries. (100) Apr.
Current Prices of Materials, Supplies and Small Tools used in Construction Work. (86) Apr. 6.
Depreciation and Rates. (14) Apr. 16.
How to Keep an English Patent Alive. (13) Apr. 21.
A New Pyrometer.* Charles E. Foster. (3) May.

Municipal.

A Review of Chicago Paving Practice.* P. E. Green, Assoc. M. Am. Soc. C. E. (54) Vol. 66.
Proposed Tests for Bituminous Compounds for Roads and Pavements, including Method of Sizing and Separating the Aggregate in Asphalt Paving Mixtures. (89) Vol. 9.
Bituminous Materials for Use in and On Road Surfaces and Means of Determining their Character. Clifford Richardson. (89) Vol. 9.
The Effect of Free Carbon in Tars from the Standpoint of Road Treatment. Prévost Hubbard. (89) Vol. 9.
Macadam Roads and Their Preservation. L. W. Page. (4) Feb.
Destructive Action of Motor Traffic on Road Surfaces and Methods of Construction to Prevent it.* W. H. Fulweiler. (2) Apr.
The Grade of Wagon Roads.* G. B. Pillsbury. (100) Apr.
Average Unit Prices and Some Details of Pavements Constructed in 1909 in a Number of Representative American Cities. (86) Apr. 6.
A New Type of Mixing Plant for Bituminous Paving Mixtures, and Data on the Cost of Constructing Asphaltic Concrete with it.* (86) Apr. 13.

* Illustrated.

Municipal—(Continued).

Experimental Work of the New York State Highway Commission in 1909 with Glutrin, and with Resurfacing with Bituminous Macadam and Asphalt Macadam. (86) Apr. 13.

Tables Showing the Amounts and Average Price of Brick, Asphalt and Creosoted Wood Block Pavements Laid in 1909 in a Number of Representative American Cities. (86) Apr. 13.

Tests of Street Flushing or Washing Machines, Department of Street Cleaning, New York City. E. D. Very. (13) Apr. 14.

Method of Constructing Sand-Clay Roads in the Middle West and Cost Data on the Construction of Four Roads of this Type. W. L. Spoon. (Abstract of Circular, U. S. Office of Public Roads.) (86) Apr. 20; (14) Apr. 16.

Preservatives for Wood Paving Blocks. Charles N. Forrest, Assoc. M. Am. Soc. C. E. (14) Apr. 16.

Cost of Highway Work in Maine. (96) Apr. 22.

Experimental Grouted Macadam Road. (86) Apr. 27.

Methods of a New York State Commission of Highways in Testing Bituminous Materials used in Road Work. (86) Apr. 27.

The Pavements of Seattle. R. H. Thompson. (Abstract of paper read before the Amer. Cong. of Road Builders.) (96) Apr. 29.

The Use of Concrete in the Construction of Pavements. James Pearson. (Paper read before the Can. Cement Assoc.) (96) Apr. 29.

The Highway System of Los Angeles County, California.* Burt A. Heinly. (60) May.

An Analysis of Illumination Requirements in Street Lighting.* Arthur J. Sweet. (3) May.

Paving Roadways having Steep Gradients. (86) May 4

Suggestions for a Rational Formula for Street Pavement Crowns.* G. B. Zahniser. (13) May 5.

Tampon Métallique pour le Pavage en Bois.* J. Toulon. (92) Mar.

Gross-Berlin, sein Verhältnis zur modernen Grossstadt-bewegung und Wettbewerb zur Erlangung eines Grundplanes für die städtebauliche Entwicklung Berlins und seiner Vororte im zwanzigsten Jahrhundert.* Albert Hofmann. (51) Serial beginning Mar. 26.

Stadtbauplan und Bauordnung im Hinblicke auf Kleinwohnungen. Josef Hermann Stübben. (53) Apr. 22.

Railroads.

The Traction of Freight Trains at Different Speeds. Clinton S. Bissell, M. Am. Soc. C. E. (54) Vol. 66.

The Equipment and Working-Results of the Mersey Railway under Steam and under Electric Traction.* Joshua Shaw, M. Inst. C. E. (63) Vol. 179.

The Single-Phase Electrification of the Heysham, Morecambe and Lancaster Branch of the Midland Railway.* James Dalziel and Josiah Sayers. (63) Vol. 179.

The Effect of Electrical Operation on the Permanent-Way Maintenance of Railways, as Illustrated on the Tynemouth Branches of the North Eastern Railway.* Charles Augustus Harrison, M. Inst. C. E. (63) Vol. 179.

Standard Specifications for Steel Tires. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.

Standard Specifications for Bessemer Steel Rails. (Amer. Soc. for Testing Materials.) (89) Vol. 9.

Standard Specifications for Open-Hearth Steel Rails. (Amer. Soc. for Testing Materials.) (89) Vol. 9.

Further Investigations of Broken Steel Rails.* Henry Fay and R. W. G. Wint. (89) Vol. 9.

Investigation of Defective Open-Hearth Steel Rails.* Robert Job. (89) Vol. 9.

Dark Carbon Streaks in Segregated Metal in Split Heads of Rails.* P. H. Dudley. (89) Vol. 9.

Report on Junctions and Swing-Bridges, Elimination of Slacking (America); Subject for Discussion at the Eighth Session of the Railway Congress.* W. G. Besler. (88) Mar.

Report on Junctions and Swing-Bridges, Elimination of Slacking (All Countries except France, Italy, Spain, Portugal, Great Britain and America); Subject for Discussion at the Eighth Session of the Railway Congress.* L. Motte. (88) Mar.

Report on Motor Vehicles (All Countries except Great Britain and America); Subject for Discussion at the Eighth Session of the Railway Congress.* L. Greppi. (88) Mar.

Report on the Operation of Switches and Signals (America); Subject for Discussion at the Eighth Session of the Railway Congress.* E. C. Carter. (88) Mar.

Report on the Use of Steel, Special Steels (America); Subject for Discussion at the Eighth Session of the Railway Congress.* R. L. Ettenger. (88) Mar.

Report on Electric Traction (Germany); Subject for Discussion at the Eighth Session of the Railway Congress.* Gleichman. (88) Mar.

* Illustrated.

Railroads—(Continued).

Report on Improvements in Locomotive Boilers (Austria-Hungary, Roumania, Bulgaria, Servia and Turkey); Subject for Discussion at the Eighth Session of the Railway Congress.* Franz Gerstner. (88) Mar.
Report on Railways and Waterways (All Countries except Great Britain and America); Subject for Discussion at the Eighth Session of the Railway Congress.* C. Colson and Louis Marlo. (88) Mar.
The Detroit River Tunnel.* Stuart C. Godfrey. (100) Apr.
Electric Traction on the Continent.* A. J. Thompson. (10) Apr.
Report of Committee on Electrification (New York Railroad Club).* (65) Apr.
Readville Locomotive Shop, New York, New Haven and Hartford Railroad.* (25) Apr.
2-8-2 Engine; Virginian Railroad.* (21) Apr.
Self-Contained Buffers for Converted Private Owners' Wagons.* (21) Apr.
Brennan's Mono-Rail System. (21) Apr.
Permanent Way for Narrow Gauge Railways.* (21) Apr.
Steel in Freight Car Construction.* C. A. Seley. (3) Apr.
Automatic Signals for Electric Railways.* Carl P. Nachod. (3) Apr.
Portable Storage Battery in Automatic Block Signal Service. H. M. Beek. (Paper read before the Ry. Signal Assoc.) (87) Apr.
Eight-Coupled Locomotives; Natal Government Railways.* (11) Apr. 1.
Tank Engines for Fast Passenger Traffic.* (12) Serial beginning Apr. 1.
The Enfield and Stevenage New Loop Line.* (12) Apr. 1.
Pole and Tie Preservation in the South. (17) Apr. 2.
Maintenance and Operating Features of the Electrified St. Clair Tunnel.* (17) Apr. 2.
Data on Tie Consumption and Preservative Treatment. (17) Apr. 2.
Track Elevation on the Chicago, Milwaukee & St. Paul at Evanston, Ill.* (15) Apr. 8.
Railway Depreciation Accounts. C. I. Sturgis. (Paper read before the National Assoc. of Ry. Commrs.) (15) Apr. 8.
The Pennsylvania Terminal at New York.* (14) Apr. 9; (17) Apr. 9; (15) Apr. 15.
Operation of Electric and Mallet Locomotives on the Great Northern. (15) Apr. 15.
The Long Island Improvements of the Pennsylvania System. (14) Apr. 16.
New Locomotives for the St. Louis & San Francisco R. R. Co.* (18) Apr. 16.
Yard and Terminal Improvements, B. & O. R. R.* (18) Apr. 16.
Automatically Lighted Signal Lamps, B. & O. R. R. Co. (18) Apr. 16.
Proposed Catenary Construction for Harlem River Branch of New York, New Haven & Hartford Railroad.* (17) Apr. 16.
An American Four-Cylinder Locomotive (Rock Island Ry.)* (12) Apr. 22.
Western Pacific Yards and Terminals.* Gustave E. Lemmerich. (15) Apr. 22.
New Locomotive Terminal of the Vandalia at Terre Haute.* (15) Apr. 22.
Railway Signalling. (96) Serial beginning Apr. 22.
Tunnels in Being and Tunnels to Come.* (19) Apr. 23.
An Instrument for Measuring Acceleration and Gradient.* (13) Apr. 28.
The Proposed Suburban Railways of Sydney.* C. O. Burge, M. Inst. C. E. (12) Apr. 29.
Grade Crossings. H. J. Pfeifer. (Abstract of paper read before the St. Louis Ry. Club.) (96) Apr. 29.
Railway Signalling.* V. I. Smart. (96) Apr. 29.
New Steel Pullman Sleeping Car.* (15) Apr. 29.
Some Engineering Features of the Detroit River Tunnel.* (15) Apr. 29.
Interurban Track and Overhead Construction. T. J. Hanlon. (17) Apr. 30.
Mallet Articulated Compound Locomotive, 2-6-6-2 Type.* (25) May.
Cost of Constructing, Equipping and Operating 36 Miles of Electric Suburban Railway, New York and Long Island Traction Co. (86) May 4.
Multiple Track Railways in New York State.* (15) May 6.
Consolidation Locomotive, Chicago, Milwaukee & St. Paul.* (15) May 6.
Automotrices Monorails à Gyroscopes Systèmes Brennan et Scherl.* Ch. Dantin. (33) Mar. 26.
Résumée, Modèles et Tables Numériques pour l'Application de la Méthode de Raccordement des Courbes.* Hallade. (38) Apr.
Note sur les Nouveaux Wagons Couverts et Fermés avec Entrée par Bouts pour le Transport de Voitures Automobiles, de la Cie P. L. M.* Laucrénon. (38) Apr.
Automotrice Electrique des Chemins de Fer Suisses pour l'Eclairage des Chantiers.* Georges Zindel. (33) Apr. 23.
Die Vorarbeiten für neue Eisenbahnen und Kanalbauten in Italien.* C. Koppe. (81) Pt. 1.
Der Bau der Eisenbahn von Aynho nach Ashendon der Great Western-Eisenbahn in England.* Karl Mentzel. (49) Pt. 1-2, 1910.
Bauausführungen der italienischen Mittelmeerbahngesellschaft.* Oder. (49) Pt. 1-2, 1910.

* Illustrated.

Railroads—(Continued).

Das Entwerfen und der Bau von Güter chuppen.* Cornelius. (49) Pt. 4-6, 1910.
Bahnsteigdächer aus Eisenbeton.* Francke. (51) Jan. 12.
Eine graphische Bestimmung von Bahnkurven bei reibungslosen, wirbelfreien Flüssigkeitsbewegungen.* Hermann Baudisch. (53) Feb. 11.
Schienen aus Manganstahl.* M. Philips. (50) Feb. 23.
Die mohammedanische Eisenbahn (Hedschasbahn).* E. A. Ziffer. (53) Mar. 4.
Bleibende Formänderungen an den Schienenenden beim schwebenden Schienenstosse.* Hans Raschka. (53) Mar. 11.
Vorschläge zur Verbesserung der Wiener Verkehrsverhältnisse. Karl Hochenegg. (53) Serial beginning Mar. 25.
Einrichtung zum Indizieren von Lokomotiven.* Rudolf Barkow. (48) Mar. 26.
Die 3/6-gekuppelten Schnellzuglokomotiven Serie 210 der k. k. österreichischen Staatsbahnen.* Metzeltin. (48) Apr. 2.
Neue Versuche zur Bestimmung des Erddrucks.* Remisch. (53) Apr. 15.
Die neue Hochgebirgsbahn von Kristiania nach Bergen.* Sigvard Heber. (48) Serial beginning Apr. 16.

Railroads, Street

An Improved Type of Point Controller for Electric Tramways.* J. P. Tierney. (77) Apr.
Shops of the Cincinnati Traction Company.* (17) Apr. 2.
Reduced Weight Semi-Convertible Car.* (17) Apr. 2.
Forest Hills Terminal, Boston Elevated Railway.* (14) Apr. 9.
Recent Practice in Motor Maintenance in Boston.* (17) Apr. 19.
Cost of the New York Subway and of Operating it. (86) Apr. 13.
Testimony on Electric Railway Construction and Operation in the Case of Manhattan Bridge Three-Cent Company.* (17) Apr. 16.
Method of Reconstructing the Washington Street Tunnel of the Chicago Railways Tunnel; a New and Economical Method of Constructing Tunnels.* (86) Apr. 20.
Traffic Conditions Influencing Passenger Subway Construction in Chicago, Ill.* (86) Apr. 20.
Cost of Operating the Manhattan Elevated Railways. (86) Apr. 20.
Method and Cost of Constructing Street Railway Track with Grouted Crushed Stone Foundation. H. L. Weber. (Abstract of paper read before the Central Elec. Ry. Assoc.) (86) Apr. 20.
The Two-Story Street Railway Terminal of the Public Service Railway, Hoboken, N. J.* John M. Barney. (13) Apr. 21.
Storage-Battery and Gasoline-Electric Cars on the Third Avenue Railroad.* (17) Apr. 23.
City Track Construction. W. A. Heindle. (Paper read before the Iowa Street and Interurban Ry. Assoc.) (17) Apr. 23.
Cost of Constructing and Operating the Electric Street Railways of Long Island City, the New York and Queens County Railway. (86) Apr. 27.
Cost of Generating Electric Power for Operating the Elevated and Subway Cars in Manhattan, New York City. (86) Apr. 27.
A Portable Stone Crushing and Concrete Mixing Plant for Street Railway Work.* (13) Apr. 28.
Cost of Operating the New York City Railway Co. Lines, 218 Miles of Electric Street Railways. (86) May 4.
Shops of the London Underground Electric Railways.* (17) May 7.
Department of Maintenance of Way and Building, Metropolitan Street Railway Company.* (17) May 7.

Sanitation.

Heating and Ventilating Plant of the Boston Safe Deposit and Trust Co.'s Building.* Charles L. Hubbard. (70) Apr.
The Disinfection of Water and Sewage. Earle B. Phelps. (2) Apr.
New Sewage Pumping Station at Glasgow.* (12) Apr. 8.
The Sewage Disposal Plant at Roebling.* (14) Apr. 9.
Sewage Disposal Ideals. W. C. Easdale. (Paper read before the Soc. of Engrs.) (14) Apr. 9; (96) Apr. 8.
Constructing a Large Brick-Lined Sewer Tunnel, Brooklyn, N. Y.* (14) Apr. 9.
A Vapor Vacuum System of Heating.* (101) Apr. 9.
Two Types of Central Heating Plants Compared. (101) Apr. 9.
Some Experiments on the Cost and Durability of Cement Drain Tile. W. H. Day. (Paper read before the Can. Cement and Concrete Assoc.) (86) Apr. 13.
Germicidal Effect of Mine Water and Tannery Wastes. (14) Apr. 16.
Constructing Concrete Sewers in Open Trench.* (14) Apr. 16.
Cost of Excavating 1,850 Cu. Yds. of Granite in Trench for Sewer Construction.* E. A. James. (Abstract from *Applied Science.*) (86) Apr. 20.
A Classification and Study of the Typhoid Statistics of the Cities of the United States. George Rodney Taylor. (13) Apr. 21.

*Illustrated.

Sanitation—(Continued).

A Notable British Court Decision Regarding Stream Pollution by the Birmingham Sewage Works. (13) Apr. 21; (14) Apr. 30.
Cost of Sewer, Muskoka, Ont.* (96) Apr. 22.
Manhole for Deep Sewer.* W. R. Worthington. (96) Apr. 22.
The Royal Commission of Sewage Disposal (12) Serial beginning Apr. 22.
A Fish Pond Filled with Purified Sewage. (14) Apr. 23.
Some English Costs of Washing Filtering Material using a Special Washing Machine. A. B. Ogden. (Abstract of paper read before the Inst. of San. Engrs.) (86) Apr. 27.
Notes on the Proposed Sewage Disposal Plant for Gloversville, N. Y. Morrell Vrooman, Assoc. M. Am. Soc. C. E. (13) Apr. 28.
The Glasgow Main-Drainage Works.* (11) Serial beginning Apr. 29.
Sewage Disposal Works at Indiana, Pennsylvania.* (14) Apr. 30.
Methods of Constructing the Western Ave. Sewer, Chicago, Ill.* (86) May 4.
Sewage Disposal Plant at Lancaster, New York.* (14) May 7.
Die Staubbeseitigung in Hüttenwerken und Giessereien.* Ernst A. Schott. (Paper read before the Versammlung der Eisenhütte Düsseldorf.) (50) Serial beginning Feb. 2.
Freilufthäuser, ein neues Bausystem für Krankenanstalten und Wohngebäude.* Sarason. (52) Mar. 15.
Eine moderne Fabrikheizung.* Max Hottinger. (48) Mar. 26.

Structural.

Progress Report of Special Committee on Steel Columns and Struts. (Am. Soc. C. E.) (54) Vol. 66.
Progress Report of Special Committee on Concrete and Reinforced Concrete. (Am. Soc. C. E.) (54) Vol. 66.
The Physical Properties of Building-Material.* William Ralph Baldwin-Wiseman, Assoc. M. Inst. C. E., and Owen Williams Griffith. (63) Vol. 179.
The Behaviour of Ductile Material under Torsional Strain with Restoration of Elasticity at Low Temperatures.* Charles Edward Larard, Assoc. M. Inst. C. E. (63) Vol. 179.
Some Results of Dead Load Bending Tests of Timber by Means of a Recording Deflectometer.* Harry D. Tiemann. (89) Vol. 9.
Disintegration of Fresh Cement Floor Surfaces by the Action of Smoke Gases at Low Temperatures. Alfred H. White. (89) Vol. 9.
Concrete Reinforced by Nails. Leon S. Moisseiff. (89) Vol. 9.
Standard Specifications for Structural Steel for Buildings. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Report of Committee on the Corrosion of Iron and Steel. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Standard Specifications for Hard-Drawn Copper Wire. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Standard Specifications for Open-Hearth Boiler Plate and Rivet Steel. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Standard Specifications for Steel Splice Bars. (Amer. Soc. for Testing Materials.) (89) Vol. 9.
Standard Specifications for Cement. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Standard Specifications for Paving and Building Brick. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Report of Committee on Preservative Coatings for Structural Materials. (Amer. Soc. for Testing Materials.)* (89) Vol. 9.
Tests of Standard I-Beams and Bethlehem Special I-Beams and Girder Beams.* Edgar Marburg. (89) Vol. 9.
The Physical Quality of Steel which has been Subjected to Compression during Solidification. Bradley Stoughton. (89) Vol. 9.
The Compressive Strength of Concrete Piers as Affected by Varying Bearing Areas.* Edgar Marburg. (89) Vol. 9.
Notes on the Bearing Value of Rods Embedded in Concrete.* Robert A. Cummings. (89) Vol. 9.
Some Tests of Bond of Steel Bars Embedded in Concrete by Three Methods.* H. C. Berry. (89) Vol. 9.
Tests of Plain and Reinforced Concrete Columns.* M. O. Withey. (89) Vol. 9.
Some of the Principles of Reinforced Concrete Construction and Some of its Practical Applications. Walter Loring Webb. (98) Apr.
New Paint Shop of the Indianapolis Traction & Terminal Company.* (17) Apr. 2.
A Lock Woven Mesh System for Reinforcing Concrete.* (22) Apr. 8.
Stability against Overturning.* W. C. Johnson. (From *Proc.*, Engrs.' Club, Univ. of Ill.) (96) Serial beginning Apr. 8.
Deep Foundation Construction in an Occupied Building.* (14) Apr. 9.
Steel-Frame Buildings at Gary, Indiana.* (14) Apr. 9.
Reinforced Concrete for Coke-Bunkers.* (66) Apr. 12.
Dry Rot in Timber. (14) Apr. 16.

*Illustrated.

Structural—(Continued).

A Storage Building for an Automobile Factory.* (14) Apr. 16.
Special Forms for and Methods of Constructing Weber Concrete Chimneys.* Carl Weber. (Abstract of paper read before the Amer. Soc. of Eng. Contrs.) (86) Apr. 20.
Erection of Steel Frame Buildings at Gary, Ind.* (14) Apr. 23.
The London County Hall.* (12) Apr. 29.
Placing Concrete Aqueduct Lining in Freezing Weather. (14) Apr. 30.
Framework of New 22d Regiment Armory, New York City; a Three-Hinged Arch Roof with Cantilever Skewback Supports.* (13) May 5.
Characteristics of Creosote. (Wood Preservation.) (14) May 7.
Note Relative au Calcul des Rotules et des Rouleaux de Dilatation.* E. Rousseau. (30) Apr.
Fondations sur Pieux en Béton.* (35) Apr.
Beitrag zur Theorie der Verbundbalken, inbesondere der genieteten Träger.* Ivan Arnovlevie. (81) Pt. 1.
Beitrag zur statischen Berechnung von Spundwänden unter Berücksichtigung besonderer örtlicher Verhältnisse. H. Ehlers. (81) Pt. 1.
Die Schönheit der Maschinen und Eisenbauten. Heinrich Pudor. (81) Pt. 2.
Uber die Berechnung mehrfach statisch unbestimmter Systeme und verwandte Aufgaben in der Statik der Baukonstruktion.* A. Hertwig. (49) Pt. 1-2.
Ausführung von Fabrik-und Schornsteinbau unter besonderer Berücksichtigung der Feuerfestigkeit der Materialien und Konstruktionsteile.* Steppes. (51) Serial beginning Sup. 7.
Kombinierte Decken-und Dachkonstruktion in armiertem Beton.* Karl Schaaf. (51) Sup. 9.
Thermograph für die Bindezeit der Zemente.* F. Quietmeyer. (80) Jan. 1.
Mörtel- und Mauerwerksfestigkeit bei höheren Wärmegraden.* (80) Jan. 4.
Untersuchung eines Schlacken-zementes.* (80) Jan. 15.
Wärmeleitfähigkeit, Porosität und Gasdurchlässigkeit feuerfester Stoffe.* (80) Jan. 20.
Aussichtsturm aus Eisenbeton auf dem Schönberg bei Pfullingen (Württemberg).* S. Zipkes. (51) Jan. 26.
Beitrag zur Berechnung von Vierendeelträgern.* A. Ostenfeld. (78) Jan. 28.
Die Folgen des Gebrauchs unrichtig zusammengesetzter Mörtel. C. Schumann. (80) Jan. 29.
Umschnürter Beton (Beton fretté).* S. Magid. (51) Jan. 26.
Die künstliche Austrocknung von Bauten.* Wendt. (51) Serial beginning Feb. 12.
Die Festigkeit von Schachtausmauerungen aus Beton und Eisenbeton.* E. Elwitz. (51) Feb. 16.
Untersuchung von Walzmaterial in den verschiedenen Verarbeitungsstufen.* (50) Serial beginning Feb. 16.
Die Gründung der neuen Rheinspeicher am Agrippina-Ufer der Stadt Cöln mit Streckmetall-umschnürten Eisenbetonpfählen.* Reinken. (51) Serial beginning Feb. 16.
Druckversuche in Buenos Aires.* E. Lufft. (78) Feb. 20.
Ermittlung der Momente von kontinuierlichen Eisenbetonplatten.* A. Burghardt. (78) Feb. 20.
Rippenfundamente in Eisenbeton für grosse Stützenlasten.* Max Bachner. (78) Feb. 20.
Bismarckturm in Glauchau.* M. Bazali. (78) Feb. 20.
Fahrzeugdepot "Persiusstrasse," Berlin.* Szalla. (78) Feb. 20.
Der Einfluss von Löchern oder Schlitzen in der Neutralschicht gebogener Balken auf ihre Tragfähigkeit.* C. Pfleiderer. (48) Feb. 26.
Wiederaufbau des Turmes der St. Michaeliskirche in Hamburg.* B. Hennicke. (51) Serial beginning Feb. 26.
Versuche über die tatsächliche Widerstandsfähigkeit von Trägern mit -förmigem Querschnitt.* C. Bach. (48) Mar. 5.
Ueber den Baugips (Stuckgips).* (80) Mar. 5.
Ein Eisenbeton Fachwerkträger von 20 m Spannweite.* Ernst Lorenz. (51) Mar. 9.
Versuch mit einem Mauerträger in Kalkmörtel.* W. Alfredo Werner. (78) Mar. 14.
Beitrag zur Durchbiegung von Eisenbetonkonstruktionen und Folgerungen hieraus.* B. Pollnow. (78) Mar. 14.
Gründungen mittels mechanischer Bodenverdichtung "System Compressol" in Aegypten.* Walther Stross. (78) Mar. 14.
Die Bulbeisendecke im Neubau des Schuppens am Moldauhafen zu Hamburg (etwa 11 000 m² Decken).* G. Kaufmann. (78) Serial beginning Mar. 14.
Die neuen Preussichen Ministerialbestimmungen über Belastungen und Materialbeanspruchungen bei Hochbauten. A. Laskus. (78) Mar. 14.
Ministerialerlass über Belastungs-annahmen und zulässige Beanspruchungen.* (80) Mar. 15.
Brandprobe mit Ziegeln und Kalksandsteinen.* (80) Mar. 17.

*Illustrated.

Structural—(Continued).

Pfahlgründung für das Palacký-Monum nt in Prag.* (78) Apr. 5.
Die Schablonendecke mit ebener Betonuntersicht von Prof. Dr. Ing. Milankovich.* Cuizza. (78) Apr. 5.
Auffällige Beobachtungen an einem Schlackenzement. (80) Apr. 9.
Ziegel und Kalksandsteine. Joannini (Hanau). (80) Apr. 14.

Topographical.

The Mille Lac Lake Survey, Minnesota; Methods and Costs. Robert Follansbee, Assoc. M. Am. Soc. C. E. (13) Apr. 7.
The Dominion Observatory.* W. F. King. (96) Apr. 8.

Water Supply.

Characteristics of Modern Hydraulic Turb[illegible] Chester W. Larner, Esq. (54) Vol. 66.
The Purification of the Water Supply of Steelton, Pennsylvania.* James H. Fuertes, M. Am. Soc. C. E. (54) Vol. 66.
The Redemption of the Great Valley of California.* A. D. Foote, M. Am. Soc. C. E. (54) Vol. 66.
The Outlet Control of Little Bear Valley Reservoir.* F. E. Trask, M. Am. Soc. C. E. (54) Vol. 66.
The Coagulating Plant of the St. Louis Water Works. Arthur I. Jacobs. (Paper read before the Engrs.' Club of St. Louis.) (1) Mar.
Analysis of Water-Power Propositions. Edwin J. Beugler. (Paper read before the Bost. Soc. of Civ. Engrs.) (1) Mar.
Irrigation and Engineering.* D. A. Willey. (10) Apr.
The Disinfection of Water and Sewage. Earle B. Phelps. (2) Apr.
Electric Irrigation Pumping in Colorado, its Effect on the Summer Load Curve of the Northern Colorado Power Company.* E. C. Reybold, Jr. (27) Apr. 7.
The Use of Hypochlorite of Lime to Disinfect the Water-Supply of Montreal, P. Q.* (13) Apr. 7.
Experiments with Hypochlorite of Lime as a Water Disinfectant at Hartford, Conn. Ermon M. Peck. (13) Apr. 7.
The Use of Hypochlorite of Lime in Connection with the Mechanical-Filtration Plant of Harrisburg, Pa. (13) Apr. 7.
A 2 000 000-Gal. Hypochlorite Water-Disinfecting Plant at Minneapolis, Minn.* J. A. Jensen. (13) Apr. 7.
Hypochlorite of Lime as an Adjunct to Mechanical Water Filtration at Quincy, Ill. W. R. Gelston. (Abstract of paper read before the Ill. Water Supply Assoc.) (13) Apr. 7.
The Use of Sulphate of Alumina and Hypochlorite of Lime in the Storage and Distributing Reservoir of the Nashville Water-Works. George Reyer. (13) Apr. 7.
Core Drilling under the Hudson River for the Catskill Aqueduct. William E. Swift, Assoc. M. Am. Soc. C. E. (13) Apr. 7.
Hydraulic Machinery and Appliances.* A. Etchells. (Paper read before the Manchester Assoc. of Engrs.) (47) Serial beginning Apr. 8.
Experiments upon the Flow of Water over Triangular Notches.* James Barr. (11) Serial beginning Apr. 8.
Turbine Pump in the Low Level Pumping Station, Montreal, Que. (96) Apr. 8.
A Novel Method of Placing Cast Iron Wells in a Water Works Crib.* (86) Apr. 13.
Designs and Contract for Rebuilding the Colorado River Dam at Austin, Texas.* (13) Apr. 14.
Failure of an Earth Dam with Concrete Core Wall at Erindale, Ontario.* Francis F. Longley, Assoc. M. Am. Soc. C. E. (13) Apr. 14.
The Slow Sand Water Filters under Construction at Reading, Pa.* Mandes Golder. (13) Apr. 14.
A 10 000 000-Gal. Pressure Mechanical Water-Filtration Plant at Duke's Farm, Somerville, N. J.* George F. Hodkinson. (13) Apr. 14; (98) Mar.
The Influence of Forests on Climate, Floods and Erosion. George F. Swain, M. Am. Soc. C. E. (13) Apr. 14.
Yorkton Compressed Air Water-Works System. F. T. McArthur. (96) Apr. 15.
The Loch Leven Power Plant.* (96) Apr. 15.
Water Powers on our Northern Slope to James Bay, Province of Ontario. L. V. Rorke. (Abstract of paper read before the Engrs. Club of Toronto.) (96) Apr. 15.
A Small Water Power Plant for a Paper Mill.* (14) Apr. 16.
Government Irrigation in the Kakima Watershed; the Tieton Canyon Canal.* Day Allen Willey. (46) Apr. 16.
Waterworks of Empalme, Mexico.* (14) Apr. 16.
An Earth Reservoir at Ogden, Utah.* (14) Apr. 16.
The Chances of Pollution in Shallow Wells for Municipal Water-Supply. Charles B. Burdick. (Abstract of paper read before the Ill. Water Supply Assoc.) (13) Apr. 21.

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*Illustrated.

Water Supply—(Continued).

A Study of Seepage Losses from Streams in Owens Valley, California.* Charles H. Lee, Jun. Am. Soc. C. E. (13) Apr. 21.
The Proposed Enlargement of the Water-Supply of Baltimore, Md. Alfred M. Quick, Assoc. M. Am. Soc. C. E. (13) Apr. 21.
Relative Corrosion of Wrought-Iron and Steel Pipes.* (Report of Comm. to the Amer. Soc. of Heating and Ventilating Engrs.) (47) Apr. 22.
The Going Value of Water-Works. (14) Apr. 23.
Leakage Tests of 11-Ft. Reinforced Concrete Pipe. (14) Apr. 23; (86) Apr. 27.
Water Purification and Pumping Plant at New Orleans, La.* (14) Apr. 23.
Cost of a 48-Inch Cast Iron Force Main. (14) Apr. 23.
Concerning the Corrosion of Metals by Water (Pipe for Water Works). George W. Fuller. (14) Apr. 23.
Failure of a Reinforced Concrete Reservoir. (14) Apr. 23.
Concrete Chute in an Irrigation Canal.* M. Nikolitch. (14) Apr. 23.
Some Los Angeles Aqueduct Costs. (13) Apr. 28.
The Production and Utilization of Ozone with Especial Reference to Water Purification.* (13) Apr. 28.
London Water Supply. (12) Apr. 29.
Reconnaissance Method of Determining the Volume of Reservoir Sites.* Horace W. Sheley, Assoc. M. Am. Soc. C. E. (14) Apr. 30.
The Ripon Water-Works Decision. (14) Apr. 30.
Sterilization of Water. Walden and Powell. (Abstract of paper read before the Amer. W. W. Assoc.) (60) May; (14) May 7.
Method and Cost of Lining Earthen Channel with Concrete.* (86) May 4.
The Los Angeles Aqueduct: Structural Details, Economic Studies, Working Organization, and Service Construction.* (86) May 4.
Sanitary Condition of Inlet Tunnel Water Supplies Immediately after Completion.* John W. Alvord and Lewis I. Birdsall. (Abstract of paper read before the Ill. Water Supply Assoc.) (13) May 5.
Some Points in the Design of Impulse-Wheel Buckets.* George M. Peck. (13) May 5.
A New Water Pressure Regulating Valve with Electrical Quick-Opening Attachment.* (13) May 5.
Water Filtration in Theory and Practice.* George C. Whipple. (Paper read before McGill Univ.) (96) May 6.
Municipal Water Softening at McKeesport. Alexander Potter. (Abstract of paper read before the Amer. W. W. Assoc.) (14) May 7.
Electricity in Water-Works Pumping.* Charles B. Burdick. (Abstract of paper read before the Amer. W. W. Assoc.) (14) May 7.
Fire Service Water-Works System of Winnipeg. H. N. Ruttan. (Abstract of paper read before the Amer. W. W. Assoc.) (14) May 7.
Flumes of Galvanized Sheets, Open Water Canals of Galvanized Metal without Rivets or Solder.* Frank C. Perkins. (101) May 7.
Poteaux Creux en Béton Armé Fabriqués Mécaniquement.* (84) Mar.
Chateau d'Eau en Béton Armé à Ixelles, prés Bruxelles.* (33) Apr. 9.
Betriebsplan für die Okertalsperre im Harz.* Ziegler. (49) Pt. 4-6, 1910.
Die Strömung von Flüssigkeiten über Flächen, Theorie der Schrauben und Tragflächen.* A. Rateau. (97) Jan. 5.
Ueber verschiedene Formen Pitotscher Röhren. H. Blasius. (From *Zentralblatt der Bauverwaltung.*) (97) Jan. 20.
Einige ausgeführte Wasserkraftanlagen.* (78) Serial beginning Mar. 14.
Das Wasserwerk der Stadt Wien in Matzendorf.* Alexander Swetz. (53) Mar. 18.
Der Nutzen des Gefällevermehrers bei Wasserkraftanlagen.* Clemens Herschel. (97) Mar. 20.
Die Ausnutzung der Wasserkräfte. Albert Loacker. (97) Mar. 20.
Die wirtschaftliche Ausnutzung der Wasserkräfte in den Beleuchtungs- und Kraftverteilungsanlagen grösserer Städte.* Norberg-Schulz. (From *Elektrotechn. Zeitschrift.*) (97) Apr. 5.

Waterways.

River Protection Work on the Kansas City Southern Railway, near Braden, Okla.* J. A. Lahmer, M. Am. Soc. C. E. (54) Vol. 66.
The Reinforced Concrete Wharf of the United Fruit Company at Bocas del Toro, Panama.* T. Howard Barnes, M. Am. Soc. C. E. (54) Vol. 66.
The Use and Care of the Current Meter as Practiced by the United States Geological Survey.* John C. Hoyt, M. Am. Soc. C. E. (54) Vol. 66.
Floods in the River Seine, Remarks on Proposed Means to Mitigate Flood Conditions at Paris. Thomas P. Roberts. (58) Mar.
Report on Railways and Waterways (all Countries except Great Britain and America); Subject for Discussion at the Eighth Session of the Railway Congress.* C. Colson and Louis Marlo. (88) Mar.
Movable Tops for Fixed Dams.* H. C. Newcomer. (100) Apr.
The Dimensions of an Artificial Waterway to Carry a Known Volume. H. L. Abbot. (100) Apr.

*Illustrated.

Waterways—(Continued).

New Lock and Dam No. 5 Monongahela River at Brownsville, Pa.* Lewis M. Adams. (100) Apr.
Unattended Fog Signal and Lighthouse at Guernsey.* (12) Apr. 8.
Proposed Harbor Development at Milwaukee, Wis. (14) Apr. 11.
The Port of Dover.* Arthur T. Walmisley. (29) Apr. 15.
Cumberland River Canalization.* Wm. W. Harts. (13) Apr. 16.
Failure of Wooden Piling due to Private Agencies and Methods of Prevention. W. Putnam. (Paper read before the Nova Scotia Soc. of Civ. Engrs.) (96) Apr. 22.
March Lake Levels. (96) Apr. 22.
The Magnitude of the Operations at Panama. (14) Apr. 23.
Waste Weir Design, New York State Barge Canal.* (14) Apr. 23.
Methods and Cost of Constructing a Concrete Lock on the Illinois and Mississippi Canal.* (86) Apr. 27.
The North Shore Channel of the Sanitary District of Chicago.* (86) Apr. 27.
The New Dock Facilities at Avonmouth, England.* (13) Apr. 28.
A Comparison of Stream Discharges Indicated by Current Meter and by Weir Formulas, Yakima River, Washington.* J. C. Stevens, Assoc. M. Am. Soc. C. E. (13) Apr. 28.
The Canadian Hydraulic Lift Locks.* Walter J. Francis. (12) Serial beginning Apr. 29.
A Proposed Freight System for the Mississippi River. (14) Apr. 30.
Preliminary Work in the Tallahatchie Drainage District. (14) Apr. 30.
Construction of the New York State Barge Canal Through Little Falls.* D. A. Watt. (14) May 7.
La Fabrication et la Manutention du Béton dans la Construction des Ecluses du Canal de Panama. Ch. Dantin. (33) Apr. 2.
La Reconstruction de la Jetée Nord de l'Entrée de la Tyne (Angleterre).* Louis Rachou. (33) Apr. 16.
Les Effets de la Crue de la Seine du 28 Janvier 1910 dans Paris et sa Banlieue.* A. Dumas. (33) Mar. 26.
Die Vorarbeiten für neue Eisenbahnen und Kanalbauten in Italien.* C. Koppe. (81) Pt. 1.
Massnahmen zur Beseitigung der Sturmflutschäden vom 30./31. Dezember 1904 an den Aussenküsten des Regierungsbezirks Stralsund.* Niese. (49) Pt. 1-2, 1910.
Das Walzenwehr im Neckar bei Poppenweiler und die Walzenwehre im Allgemeinen.* Th. Becher. (51) Serial beginning Jan. 29.
Der Eisgang und das Hochwasser der Düna im Frühjahr 1909. A. Pabst. (52) Feb. 15.
Das Wehr in den St. Andrews-Stromschnellen.* H. P. Borden, A. M. Can. Soc. C. E. (48) Mar. 12.
Das Seine-Hochwasser in Paris vom Jänner 1910.* (53) Mar. 18.

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*Illustrated.

Vol. XXXVI. MAY, 1910. No. 5.

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INSTITUTED 1852

PAPERS AND DISCUSSIONS

CONTENTS

PLATES

Vol. XXXVI. MAY, 1910. No. 5.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

PAPERS AND DISCUSSIONS

REINFORCED CONCRETE PIER CONSTRUCTION.*

By Eugene Klapp, M. Am. Soc. C. E.

A private yacht pier, built near Glen Cove, Long Island, has brought out a few points which may be of interest. It is an example of a small engineering structure, which, though of no great moment in itself, illustrates the adoption of means to an end that may be capable of very great extension.

The problem, as submitted to the writer, was to construct a yacht landing at East Island, on the exposed south shore of Long Island Sound, in connection with the construction at that point of an elaborate country residence. The slope of the beach at this point is very gradual, and it was specified that there should be a depth of at least 4 ft. of water at low tide. Soundings indicated that this necessitated a pier 300 ft. long. It was further specified that the pier should be to some extent in keeping with the scale of the place being created there, and that a wooden pile structure would not be acceptable. Besides these esthetic conditions, wooden piles were rejected because the teredo, in this part of the Sound, is very active. At the same time, the owner did not care to incur the expense of a masonry pier of the size involved. Also, it was desired to unload on the pier all material for the house and grounds during construction, and coal and other supplies thereafter, thus necessitating a pier wide enough to allow access for a cart and horse and to provide room for turning at the pier head.

*This paper will not be presented at any meeting, but written communications on the subject are invited for publication with it in *Transactions*.

PLATE CI.
PAPERS, AM. SOC. C. E.
MAY, 1910.
KLAPP ON
REINFORCED CONCRETE PIER CONSTRUCTION.

YACHT PIER NEAR GLEN COVE, N. Y.

Comparative designs and estimates were prepared for (*a*) a pier of ordinary construction, but with creosoted piles; (*b*) a concrete pier on concrete piles; and (*c*) for a series of concrete piers with wooden bridge connections. The latter plan was very much the best in appearance, and the calculated cost was less than that of the pier of concrete piles, and only slightly more than that of creosoted piles, the latter being only of a temporary nature in any case, as it has been found that the protection afforded by creosote against the teredo is not permanent.

At this point on the Sound the mean range of the tide is about 8 ft., and it was determined that at least 5 ft. above mean high water would be required to make the underside of the dock safe from wave action. There is a northeast exposure, with a long reach across the Sound, and the seas at times become quite heavy. These considerations, together with 4 ft. of water at low tide and from 2 to 3 ft. of toe-hold in the beach, required the outer caissons to be at least 20 ft. high.

To construct such piers in the ordinary manner behind coffer-dams, and in such an exposed location, was to involve expenditure far beyond that which the owner cared to incur. The writer's attention had shortly before been called to the successful use of reinforced concrete caissons on the Great Lakes for breakwater construction, by Major W. V. Judson, M. Am. Soc. C. E., and under patents held by that officer. It seemed that here was a solution of the problem. These caissons are constructed on the shore, preferably immediately adjoining the work. After thorough inspection and seasoning, they are usually launched in a manner somewhat similar to a boat, are towed into position, sunk in place, and then filled with rip-rap.

In this case what was needed was a structure that could be constructed safely and cheaply in the air, could then be allowed to harden thoroughly, and could finally be placed in accurate position. The weights to be supported were not great, the beach was good gravel and sand, fairly level, and, under favorable circumstances of good weather, the placing of the caissons promised to be a simple matter. Therefore, detailed plans were prepared for this structure.

An effort was made to preserve some element of the yachting idea in the design, and bow-string trusses, being merely enlarged gang planks, were used to connect the caissons.

The pier was originally laid out as a letter "L," with a main leg

of 300 ft. and a short leg of 36 ft. The pier head consisted of eight caissons in close contact, and was intended to form a breakwater, in the angle of which, and protected from the wave action, was to be moored the float and boat landing. After the first bids were received, the owner wished to reduce the cost, and every other caisson in the pier head was omitted, so that, as built, the pier contains eight caissons and five 53-ft. trusses. The caissons supporting the trusses are 8 ft. wide and 12 ft. long, and those in the pier head are 12 by 12 ft. On account of the shoal water and the great height of the outer caissons in comparison with their cross-section, it seemed advisable to mould them in two sections. The reinforcement in the side walls consisted of round $\frac{1}{2}$-in. rods horizontally, and $\frac{3}{8}$-in. rods vertically, spaced as shown on Fig. 1, together with cross-diaphragms as indicated.

The caissons were reinforced for exterior pressures, which were to be expected during the launching and towing into position, and also for interior pressures, which were to be expected at low tide, when the water pressure would be nothing, but the filling of the caissons would be effective. The corners were reinforced and enlarged. In order to secure a proper bedding into the sand foundation, a 12-in. lip was allowed to project all around the caisson below the bottom. In the bottom there was cast a 3-in. hole, and this was closed by a plug while the lower section was being towed into place.

The question of the effect of sea water on the concrete was given much thought. The writer is unable to find any authoritative opinions on this subject which are not directly controverted by equally authoritative opinions of a diametrically opposite nature. He thinks it is a question that this Society might well undertake to investigate promptly and thoroughly. There can be no question that there are many distressing instances of failures due to the action of sea water and frost on concrete, and that many able and experienced engineers in charge of the engineering departments of the great transportation companies have simply crossed concrete off their list of available materials when it comes to marine construction. It is a subject too large in itself to be discussed as subsidiary to a minor structure like the one herein described, and though many have rejected concrete under these conditions, other engineers equally conservative are using it freely and without fear.

The writer consulted with his partner and others at some length, and considering all the advantages to accrue by the use of these concrete caissons, decided to do so after taking all known precautions.

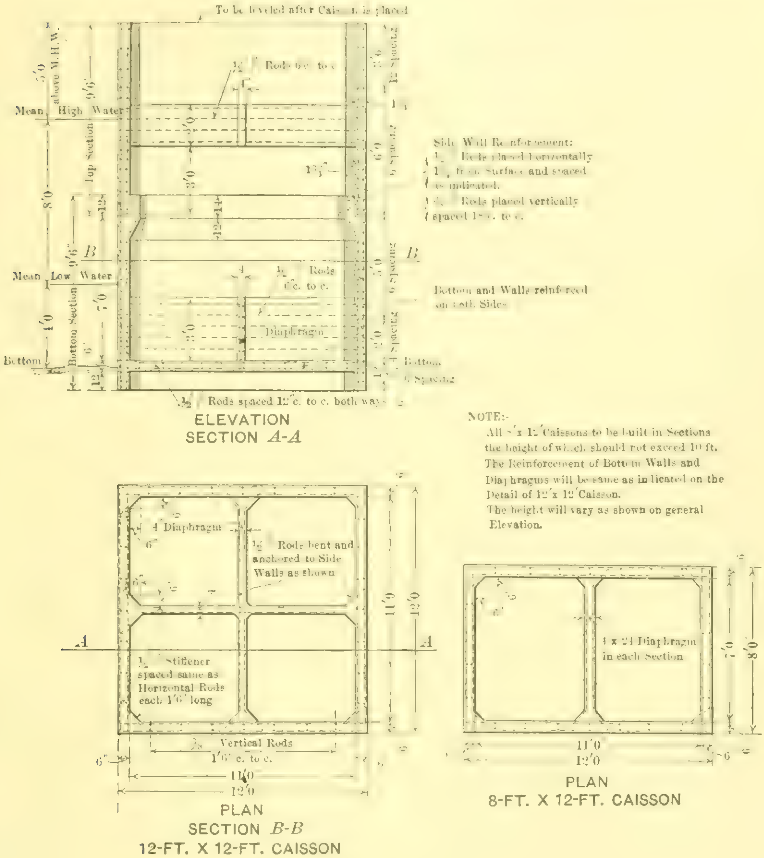

FIG. 1.

These precautions consisted in:

First, the use of cement in which the chemical constituents were limited as follows:

It was specified that the cement should not contain more than 1.75% of anhydrous sulphuric acid (SO_3) nor more than 3% of magnesia (MgO); also that no addition greater than 3% should have been made to the ingredients making up the cement subsequent to calcination.

Secondly, to secure by careful inspection the most completely homogeneous mixture possible, with especial care in the density of the outer skin of the caissons.

Thirdly, a prolonged seasoning process before the new concrete should be immersed in the sea water.

In addition to these well-known precautions, it was decided to try the addition to the cement of a chemical element that should make with the free lime in the cement a more stable and indissoluble chemical combination than is offered by the ordinary form of Portland cement. This was furnished by the patent compound known as "Toxement," which is claimed by the inventor to be a resinate of calcium and silicate of alumina, which generates a resinate of lime and a silicate of alumina in crystalline form. It is further claimed that each of these materials is insoluble in sodium chloride and sodium sulphate, 3% solution. It was used in all the caissons, excepting Nos. 1 and 2, in the proportions of 2 lb. of Toxement to each 100 lb. of cement. The first two caissons were not thus treated, and will be held under close observation and comparison with the others, which were treated with this compound.

The mixture used was one of cement (Pennsylvania brand), two of sand, and four of gravel. The sand and gravel were from the nearby Cow Bay supply, and screened and washed. None of the gravel was larger than ½ in., grading down from that to very coarse sand. The sand was also run-of-bank, and very well graded.

The caissons, after being placed, were filled with sand and gravel from the adjoining beach up to about mean high-water mark, and the edges outside all around were protected from tidal and wave scour by rip-rap of "one man" stone.

The trusses were constructed on a radius of 34 ft., with 8 by 8-in. chords, 6 by 6-in. posts, and 1-in. rods. The loading was figured as a loaded coal cart plus 100 lb. per ft. All lumber was clear yellow pine, except the floor, which was clear white oak. The pipe rail and all bolts below the roadway level, and thus subject to frequent wettings by salt water, were of galvanized iron. The trusses were set 9 ft. 9 in. apart on centers, giving a clear opening of 8 ft. between the wheel guards under the hand-rails. The fender piles were creosoted. The float was 18 ft. long and 12 ft. wide.

A contract was let to the Snare and Triest Company, and work

was commenced early in August, 1909. The first caisson was poured early in September, and the last about the beginning of October.

The caissons were all cast standing on parallel skids at about mean high water. It was first intended to construct a small marine railroad and launch the caissons in that manner, rolling them along the skids to the head of the marine railway. This plan was abandoned, however, and by sending in at high tide a powerful derrick scow, many of the caissons were lifted bodily from their position and set down in the water, towed to place and sunk in position, while the others, mostly the upper sections, were lifted to the deck of the scow and placed directly from there in their final position. There was not much difficulty in getting them to settle down to a proper bearing. Provision had been made for jetting, if necessary, but it was not used. In setting Caisson No. 2 a nest of boulders was encountered, and a diver was employed to clear away and level up the foundation. The spacing was accomplished by a float consisting of two 12 by 12-in. timbers, latticed apart, and of just sufficient length to cover the clear distance between the caissons. The first caissons being properly set inshore, the float was sent out, guyed back to the shore, and brought up against the outer edge of the set caisson. The next caisson was then towed out, set against the floating spacer, and sunk in position. There was some little trouble in plumbing the caissons, but, by excavating with an orange-peel bucket close to the high side and depositing the material against the low side, they were all readily brought to a sufficiently vertical and level position to be unnoticed by sighting along the edge from the shore.

The trusses were all constructed in the contractor's yard at Bridgeport, and were towed across the Sound on a scow. They were set up and braced temporarily by the derrick boat, and then the floor and deck were constructed in place.

On December 26th, 1909, a storm of unusual violence—unequaled in fact for many years—swept over the Sound from the northeast; the waves beat over the pier and broke loose some floor planks which had been only tacked in position, but otherwise did no damage, and did not shift the caissons in the least. The same storm partly destroyed a pier of substantial construction less than a mile from the one in question.

Unfortunately, the work was let so late in the summer, and the

restrictions as to seasoning the concrete were enforced so strictly, that the work of setting the caissons could not be commenced until November 11th, thus the entire construction was forced into the very bad weather of the late fall and early winter. As this involved very rough water and much snow and wind, the work was greatly delayed, and was not completed until the middle of January. The cost of the entire dock was about $14 000.

The writer believes that the cost was much less than for masonry piers by any other method of construction, under the existing circumstances of wind, tide, and exposure.

It would seem that for many highway bridges of short span, causeways, and similar structures, the use of similar caissons would prove economical and permanent, and that they might be used very largely to the exclusion of cribwork, which, after a decade or so, becomes a source of constant maintenance charges, besides never presenting an attractive appearance. Finally, in bridges requiring the most rigid foundations, these caissons might readily be used as substitutes for open wooden caissons, sunk on a prepared foundation of whatever nature, and still be capable of incorporation into the finished structure.

Vol. XXXVI. MAY, 1910. No. 5.

AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS AND DISCUSSIONS

REMEDIES FOR LANDSLIDES AND SLIPS ON THE KANAWHA AND MICHIGAN RAILWAY.

By R. P. Black, Assoc. M. Am. Soc. C. E.

To be Presented September 7th, 1910.

To reach the Kanawha Valley Coal Fields of West Virginia, the southern portion of the Kanawha and Michigan Railway, for 93 miles (from Point Pleasant to Gauley Bridge, W. Va.), is located on the east side of the Great Kanawha River. For about one-third of this distance the road is close to the banks of the river, on a hillside location, where there is practically no valley, the mountains rising directly from the stream.

Owing to the character of the soil, there is considerable trouble, due to landslides and slips, the term slips being used where the fill, or embankment under the tracks, settles or slips toward the river.

Excessive rains occur during the winter, and small landslides are numerous, but do little damage; in most cases the water rushing from the mountains brings with it one or two uprooted trees and a few yards of earth. There is much more trouble with the larger landslides, that is, where the whole hillside gradually slips down toward the river, pushing the track ahead of it, and giving bad line and surface. At some places the track is not only pushed out of line but raised.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

Landslides occur in almost every case where the hill or mountain side has been cleared of all forest. The top soil, or earth above the rock, which varies in depth from 8 to 20 ft., is mucky clay, which holds water in every low place, apparently being impervious. This clay soil soon becomes saturated, soft, and mucky, and, not having any roots or vegetation to hold it in place, and being on a slope, starts a downward movement, slipping on the rock, covering the ditches and ballast of the track, and pushing it out of line. These so-called landslides do not come down at once, but move slowly, thereby causing no immediate danger. In several places reverse curves have to be given to the alignment, in order to keep the track in surface.

At Point Pleasant, where there was a small landslide, the earth, as it came in, was removed by a steam shovel at the toe of the slope. The soil at this point was slipping on an inclined stratum of rock, the top of which was smooth and had the appearance of soapstone.

In cases where it was impracticable to remove the slide, the top-soil drainage system on the hillside above was at first tried, but did not work successfully, as the ditches, due to the slippery soil, soon filled up. It appeared that the small amount of surface water collecting in the low places caused by the roughened surface was sufficient to cause the slipping.

At Leon, where considerable expense was incurred in maintaining the track around a slide, the hillside was removed, and the track, for 2 000 ft., was relocated on the rock bottom, obtained by cutting back to a side-hill location. By this method the entire landslide was removed and the track put on rock bed, thereby doing away with the trouble, at a cost of $20 000.

At Cannelton, where the largest slow-moving landslide occurred, the main track had been pushed out of line. Reverse curves were made, in order to get back to the alignment on either side, but, on account of the continual lining out of the track, the curves became too sharp for operation, and the side track between the hillside and the main track became completely covered. As this slide was of such extent and depth, Fig. 1, it was out of the question to remove it in order to get back far enough for a rock sub-grade, as at Leon. The change of line not being feasible, it was proposed to remove part of the landslide, permitting the relocation of the tracks on their original alignment and, after completing this, to protect them from further slides.

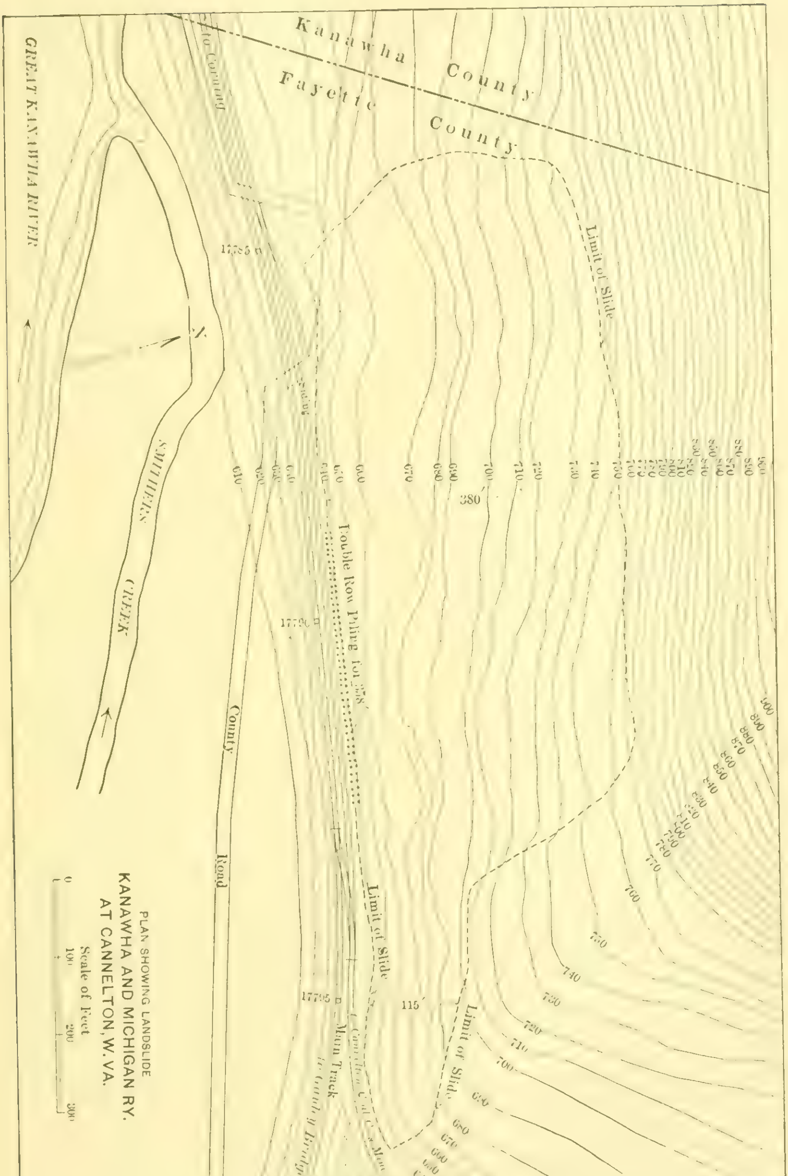

GREAT KANAWHA RIVER
Kanawha County
Fayette County
Limit of Slide
SMITHERS CREEK
County Road
Double Row Piling for 358'
Main Track
PLAN SHOWING LANDSLIDE
KANAWHA AND MICHIGAN RY.
AT CANNELTON, W. VA.
Scale of Feet

FIG. 1.

A steam shovel was cut in at one end, and removed enough of the landslide to allow the two tracks to be changed to their original location. After the shovel had worked about three days a slide occurred one night, half burying the shovel. Steps were then taken to hold back the hillside before further slides could develop. This was done successfully by driving two parallel rows of piling, 5 ft. apart, about 3 ft. from center to center, as shown on Fig. 2. The upper rows, against the hill, were backed with 3-in. plank, the front rows being driven against this brace in order to aid in supporting the upper row. A 10 by 10-in. stringer was placed against the upper row, and from this 8 by 8-in. braces were carried diagonally, at an angle of 45°, to the lower row of piles, and these were sawed off at the ground level. Steel

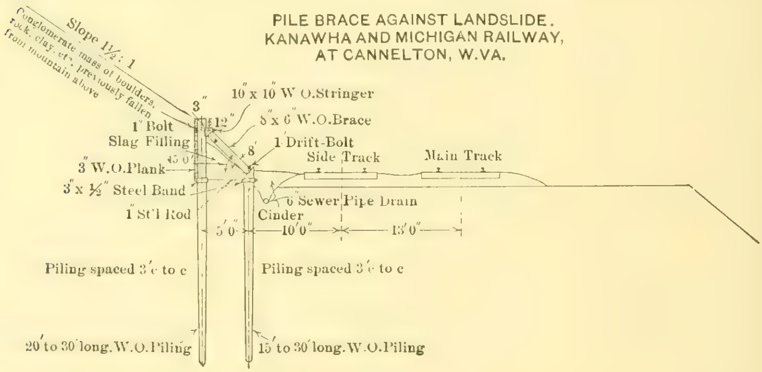


FIG. 2.

bands, with 1-in. rods to hold the two sets of piling together, were put on about 8 in. below the top of the brace pile. The depth of penetration of the piling varied from 15 to 30 ft. The piling was selected large white oak, and oak timber was used for the stringers and braces. Moving the shovel ahead about 30 ft., then cutting it back, and driving the piling as shown, constituted a day's operation. The work was completed successfully without further serious landslides. In four weeks about 12 000 cu. yd. of earth were removed, the track was thrown back to its original alignment, and the landslide was stopped. This work cost $16 000.

The upper limit of the slide is about 135 ft. above the track. The slide consists of about 200 000 cu. yd. of moving earth. This work was done in the spring of 1907, and has been successful. At several

places, due to excessive pressure, the braces have been embedded in the stringers. The earth from the top of the piling was given a slope of 1½ to 1; at several other points smaller slides have been stopped with one row of piling. The piles were driven 3 ft. apart, center to center, and cut off 3 ft. above the top of the rail, the ground above being given a slope of 1½ to 1. At one or two places, where one row was not sufficient, the trouble was stopped with brace piling. At points where the single row of piling showed signs of leaning, due to the pressure against that part of the piling above ground, this overturning, apparently due to too much length above ground, was stopped by cutting off the piling 3 ft. above the ground and giving the earth above it a slope of 1½ to 1.

In contending with landslides of this character in West Virginia, all that seems to be necessary is to obtain a good toe hold, which stops the movement of the earth above. The so-called slow-moving landslides on the Kanawha and Michigan Railroad have been stopped successfully by one of these methods.

Slips.—The term, "slips," as the conventional name indicates, is applied to places where the soil slides into the river. These slips occur when the roadbed is constructed on a fill, ranging in depth from 5 to 10 ft., across narrow flats, between the hill and the river. Due to the constant movement of the earth, no trees grow on the land between the river and the railroad. The ground slips gradually into the river where, from time to time, its toe is cut away by the current.

The peculiarity of these slips is the fact that they may continue for one or more seasons without giving any trouble. Slips are due to high water and not to surface water. A quick rise and fall of the river will not cause the soil to move, but continued high water, or several successive floods, will start the slipping action.

In the spring of 1908, the length of track affected by the slips was 7 600 ft., necessitating, at several different points, the maintenance of speeds ranging from 6 to 20 miles per hour for five months, until the dry season, when this slipping action stopped. On Plate CII is shown a cross-section of the Brighton slip, which gave the greatest trouble. The section is taken at right angles to the track, the information for which was obtained by levels and test rods driven to rock. A stratum of rock, below the earth, slopes toward the river, ranging from 1 : 0.2 to 1 : 1. This rock is covered by successive layers of red clay,

varying from 3 to 6 ft. in thickness. Immediately above the rock, and in thin seams, from 4 to 8 in. thick, between the layers of clay, is found a quicksand mixed with fine clay. When the quicksand and fine clay become thoroughly saturated with water, the mixture affords a smooth surface over which the top soil or successive layers of clay slide toward the river. After high water these seams of quicksand can be traced readily by the water seepage. The quicksand is very slimy, and contains no grit. The water must remain over the ground long enough to force its way back into this quicksand and saturate well before the slipping action can take place.

In 1908, in order to keep the track safe, the gangs on four sections were increased from three—the normal force—to ten men each, and these increased forces were maintained for four months. The tracks had to be resurfaced and lined continually. At three different times, it was necessary to put on filling material and ballast in order to keep the track up to grade. This entailed a cost of $4 400 more than the normal expenses for the year. The track over the slips was not only costly to maintain, but dangerous, due to wrecks resulting from derailments on account of rapid settlement of the roadbed.

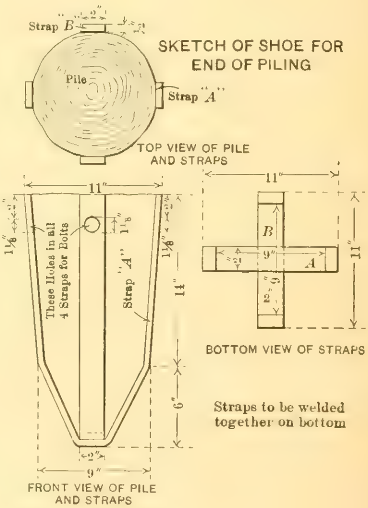
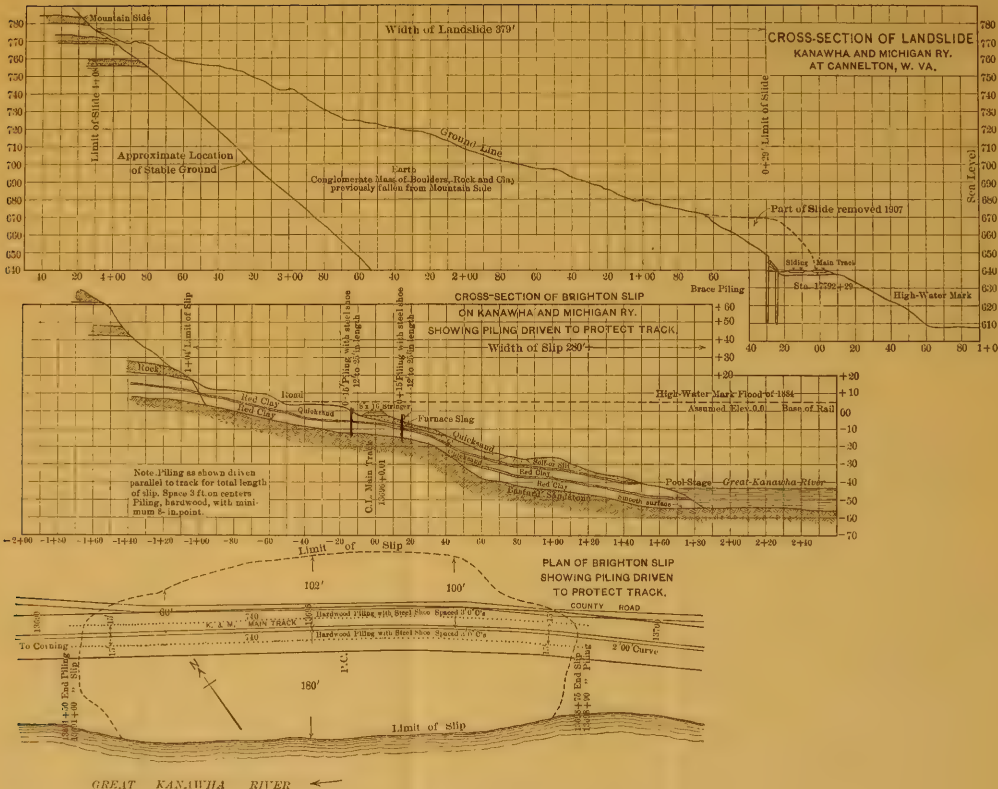


FIG. 3.

At Poca, where a trestle was maintained over a slip for about 800 ft., due to the heavy cost of changing the alignment, the trestlework was filled with heavy quarried rip-rap, and the fill was widened so that the stone reached the river's edge. The weight of this stone fill caused settlement, but, after adding stone from time to time for five years, the roadbed became solid. It is thought that the stone fill settled to the rock stratum below the slip, thereby stopping the movement.

For slips at other points where small fills were maintained, several remedies were suggested, one being to construct, at the river's edge,


CROSS-SECTION OF LANDSLIDE
KANAWHA AND MICHIGAN RY.
AT CANNELTON, W. VA.
Mountain Side
Width of Landslide 379′
Limit of Slide 1+08
0+29 Limit of Slide
Ground Line
Approximate Location of Stable Ground
Earth
Conglomerate Mass of Boulders, Rock and Clay previously fallen from Mountain Side
Part of Slide removed 1907
Siding
Main Track
Sta. 17792+29
Brace Piling
High-Water Mark
Sea Level
CROSS-SECTION OF BRIGHTON SLIP
ON KANAWHA AND MICHIGAN RY.
SHOWING PILING DRIVEN TO PROTECT TRACK.
Width of Slip 280′
1+04 Limit of Slip
0-15 Piling with steel shoe 12 to 25 in length
0+15 Piling with steel shoe 12 to 25 in length
Rock
Road
Red Clay
Red Clay
Quicksand
8″x 16″ Stringer
Furnace Slag
Quicksand
Quicksand
Soft or Silt
Red Clay
Red Clay
Eastard Sandstone
Smooth surface
High-Water Mark Flood of 1884
Assumed Elev. 0.0
Base of Rail
Pool Stage
Great Kanawha River
C.L. Main Track
13696+0.01
Note. Piling as shown driven parallel to track for total length of slip. Space 3 ft. on centers Piling, hardwood, with minimum 8-in. point.
Limit of Slip
102′
100′
PLAN OF BRIGHTON SLIP
SHOWING PILING DRIVEN
TO PROTECT TRACK.
COUNTY ROAD
K. & M. MAIN TRACK
Hardwood Piling with Steel Shoe Spaced 3′0″ C's
Hardwood Piling with Steel Shoe Spaced 3′0″ C's
To Corning
2°00′ Curve
P.C.
180′
13691+50 End Piling
13691+60 " Slip
13698+75 End Slip
13698+90 " Piling
Limit of Slip
GREAT KANAWHA RIVER

a wall which would act as a toe to hold back the moving soil. Owing to the necessary height of the wall, however, this was deemed too costly. At Brighton and Leon slips, where the alignment could not be changed, the remedy shown on Plate CII was proposed, the scheme being to drive two rows of piling, one on each side of the track, with a track-driver, the piling to be equipped with steel shoes (Fig. 3) for penetrating the rock strata. It was supposed that, with the toe hold in the rock, and the pinning together of the successive moving clay strata, this slipping action in the vicinity of the track would be stopped.

In the spring of 1909, test piling was driven for a distance of 50 ft. in the center of the Brighton slip. Transit observations taken from a base line, showed that the piling did not move any appreciable distance. The track held up well within the limits of the piling where, as on either side, it had been necessary to resurface continually.

The test being successful, two rows of piling were driven during December, 1909, on either side of the track at the Brighton slip, and between its limits, for a distance of 740 ft. The piles were equipped with steel shoes and were driven 3 ft. apart, center to center, on the down-hill side. Continuous 8 by 16-in. timber bracing was bolted to the piling. The work was done with a self-propelling track-driver. A temporary spur track was constructed at one end of the slip, thus dispensing with the services of a work train. The cost of this work was as follows:

Hardwood piling, 8 075 ft. at 13 cents	$1 049.75
Steel shoes, 12 690 lb. at 3 cents	380.70
Labor	856.35
Fuel, etc.	120.00
Total	$2 406.80

Up to the present time, this remedy has been successful.

At another point, where the rock strata are not at great depth, it is proposed to go down the hillside about 20 ft. from the track, put down holes about every 20 ft., and blast the smooth surface of the rock. Thus, by roughening the surface and destroying the stratification, the sliding of the clay may be stopped.

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PAPERS AND DISCUSSIONS

This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE ULTIMATE LOAD ON PILE FOUNDATIONS: A STATIC THEORY.*

By John H. Griffith, Assoc. M. Am. Soc. C. E.

Introduction.—In one of his discussions as to the ultimate bearing power of pile foundations, the late E. Sherman Gould, M. Am. Soc. C. E., stated that the theories of Goodrich had mathematically exhausted the subject, referring, of course, to a dynamic analysis. It is interesting, therefore, to note an entire departure from the usual procedure in a treatment proposed by Desmond† in which he studies a concrete pile purely by static methods.

A perfected static analysis would appear to have certain advantages over the older methods in that it will either eliminate altogether, or relegate to a sphere of minor importance, a number of elements the real significance of which, even in a most precise dynamic theory, is destined to be rather vague and indeterminate. One might cite, for example, the case where the pile bounds back or slowly rises after driving, owing possibly to a resiliency or sponginess of the soil, or perhaps to a buoyant effect of the latter on the pile. Such a phenomenon as brooming of the head might likewise be cited. When the engineer analyzes such perplexing problems as compression of the hammer or the pile, questions of impact, friction of the guides, measurements of velocity, and the like, the real import of any one of which will

* This paper will not be presented at any meeting, but written communications on the subject are invited for publication with it in *Transactions*.

† *Transactions*, Am. Soc. C. E., Vol. LXV, 1909, Discussion on paper, "Concrete Piles," p. 498, by Mr. Thomas C. Desmond.

require involved analyses by the accomplished physicist, he may often be constrained to take the viewpoint of such eminently practical engineers as Haswell and Gould as to some of these matters. In fact, with any final working formula, to measure such an uncertain element as the penetration and neglect altogether the earth factors (as is tacitly done in any of the representative Sanders' expressions) would seem to seek a sort of negative magnification of the effect, reading, as it were, through the wrong end of the telescope, or taking observations at the short arm of the lever. Goodrich remarks* that:

"The liability to error is so enormous with small penetrations that no penetration should be trusted much less than 1 in., and no formula can be guaranteed within a reasonable percentage of error for less penetrations."

He shows that: "With a total penetration as large as 4 ins. (which is seldom observed), a variation of $\frac{1}{8}$ in. would make this penetration liable to 3% error."

Such a static theory will further endeavor to eliminate what Maxwell has called the historical element. The analysis of Desmond, for example, is not concerned with the load status a minute after driving, nor a year after, but rather in that indefinite period of time when the condition of the earth may be said to correspond with that minimum of stored energy which exists or tends to exist in Nature for stable equilibrium; or, if this element is to enter the analysis explicitly, it can only serve to render the problem more determinate. The dynamic analysis at best can only cover the situation in the period immediately after driving.

Then there are such formidable questions as the number of blows to refusal, the effect of the earth clinging to the pile, and many items of like moment.

In a larger sense, however, the static treatment should be viewed as complementary to the older method. A perfected theory of the pile will neither be confined exclusively to a study of the left-hand member of the equation of work, nor, in the other case, to the $\int Pds$ of the right-hand member, but, taking a unitary conception of the problem, will seek to include all variables and a determination of their effect on the status of ultimate load.

* *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 205.

It is to be hoped that Desmond's discussion may be the nucleus for a literature considering this larger view; further, that it may stimulate engineers to extend their experiments on earth pressures, hitherto confined to retaining walls, to include examinations of pile phenomena as well, the pile being in many respects a sort of inverted retaining wall in its analytical features.

The able engineers who have followed exclusively in the paths pioneered by Rankine and Moseley seem finally to have reached the proverbial blind alley in their attempts to solve the pile problem purely as a dynamic proposition; but Rankine* himself, it should be considered, at least implicitly suggested the static method in his attempt to figure the drawing power of screw-piles and the pressure on foundations. Any advance, however, in this field, seems to have been restricted, at least in America, by a too close adherence to his ellipse of stress principle, a rather subsidiary relation in the paper mentioned, which, while it may serve its purpose in elementary problems of the retaining wall, is not an efficient tool for a general investigation in the theory of earth pressure.

The writer will offer herein a few criticisms on the static method as it has been presented to date, and will outline some views as to its development along rational and empirical lines. In doing this, the paper will necessarily be confined to little more than an examination of the premises of the older authorities and an attempted statement of the problem. Owing to the scarcity of experimental data directly bearing on this subject, and an inadequate literature, such an investigation must be largely *a priori* in its nature, paving the way for a more rigorous analysis and suitable experimentation by others.

Existing Methods.—In the first and later editions of his "Civil Engineering" (1895), Patton gives the following equations for the "total bearing power of the pile":

$$P = A\,w\,x\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2 + \frac{S\,f\,w\,x}{2}\left(\frac{1 - \sin.\,\phi}{1 + \sin.\,\phi}\right) \text{ minimum,}$$

$$P' = A\,w\,x\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2 + \frac{S\,f\,w\,x}{2}\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right) \text{ maximum,}$$

where w = the weight of a cubic foot of the material,

A = cross-section of the pile at the bottom,

* *Philosophical Transactions*, Royal Society, 1857.

x = depth of the pile in the soil,

S = area of exterior surface of the pile,

f = coefficient of friction of earth on the pile surface.

The expression, $w\,x\left(\frac{1 \mp \sin.\,\phi}{1 \pm \sin.\,\phi}\right)$, is the intensity of lateral normal pressure, minimum and maximum, on the surface of the pile. When multiplied by the proper coefficient of friction of wood on earth, this resulting tangential stress, when summed over the whole peripheral surface of the pile, gives, according to the Patton theory, the frictional resistance of the soil. The first terms in the right-hand members of each equation give the pressure on the base. Patton remarks:

"If proper values of ϕ, S, and f in equations above are determined by experiment, it would seem that these formulæ would produce better and more reliable results than the more common formulæ would."

The solution given is the earliest direct attempt to solve the problem (other than that given by Rankine, before mentioned) that has come to the writer's attention.

Very recently, Professor Vierendeel (University of Louvain, Flanders) has treated the subject in more detail, together with the dynamic method, in a comprehensive work* in which he gives the formula:

$$R = \pi\, D\, f\, w\, \frac{1 + \sin.\,\alpha}{1 - \sin.\,\alpha}\, \frac{L^2}{2} = 1.5\, D\, f\, w\, L^2\, \frac{1 + \sin.\,\alpha}{1 - \sin.\,\alpha},$$

which he deduces by the principle of work, where R = the ultimate load, D = the mean diameter of the pile, L = the depth of penetration, w is the unit weight, and α is the natural talus.

It will be seen by a little study that the foregoing methods are practically in agreement with the aforementioned treatment by Desmond, in that each makes use of the ordinary Rankine relation, multiplies by a friction factor, and integrates the stress in one form or another over the entire surface in contact with the soil.

Viewed as an empirical expedient, such equations should commend themselves to engineers for practical use in fixing load limits. In this capacity, they will doubtless excel the ordinary Sanders' energy formulas, if constants are properly evaluated from test loadings, as suggested by Patton.

* "Cours de Stabilité des Constructions" (Tome VI, 1907).

A true empirical basis for the study of the pile problem may be established by actual laboratory tests more easily than in the case of the retaining wall; for if loads at incipient motion are measured on a model pile which passes entirely through a reservoir of sand, having a hole in the base for egress of the pile, actual values of the total peripheral friction may be obtained and studied with respect to its variation for a variety of perimeters. Combined effects of basal and lateral stress could be obtained, of course, by independent experiments. It is important, however, that the base and lateral effects should be differentiated if they are to be studied and analyzed.

If, however, the methods given by these authors are to be construed as rational propositions, then, in their present form, they appear to be open to serious criticism, because, in making use of Rankine's expression for the intensity of stress, they violate his principle of conjugate stresses, which in this particular case makes the expression of the form, $w\,x\left(\frac{1 \mp \sin.\ \phi}{1 \pm \sin.\ \phi}\right)$, a principal stress, that is, one purely normal to the surface of the pile and having its maximum value. Consequently, the notion advanced by these writers of multiplying this principal stress by a friction factor is incompatible with the well-known principles of mechanics of stress.

Empirically, however, there is as much justification for the use of such types of formulas as there is for any of the present-day column formulas or some of the beam applications. The forms of the expressions are correct enough, as far as Rankine's intensity of lateral pressure is concerned, but, of course, the angle, ϕ, must be considered as an arbitrary parameter to be determined for certain soils, and not as the angle of repose or internal friction. Just what the deviation of this parameter from the angle of internal friction will be must be determined by such experiments as have been suggested or by actual tests in the field for ultimate loading.

A general criticism, of course, is that the problem in its final analysis will not lend itself to any such elementary forms as a Rankine solution may be expected to give. Any theory must experience that evolution characteristic not alone of the dynamic analysis of the pile and the retaining wall, but of all the classical problems in engineering. In such an evolution the Rankine theory rightfully assumes its place as a primitive, true enough under its own premises, but of

which the premises are not general enough to include the whole range of phenomena either of the pile or of the retaining wall.

The Rankine Theory.—In view of the fact that the Rankine theory has already taken its place as the basis for a static analysis of the pile, it is important that it be rigorously stated. The following is conceived to be an exact solution, with no assumptions except those contained in Rankine's premises.

Consider a pulley-shaped foundation, with data as indicated in Fig. 1, which, as in the case treated by Desmond, may be a concrete or timber pile jetted or driven to place. Any form of cross-section might be taken, but, for simplicity, it is assumed as circular.

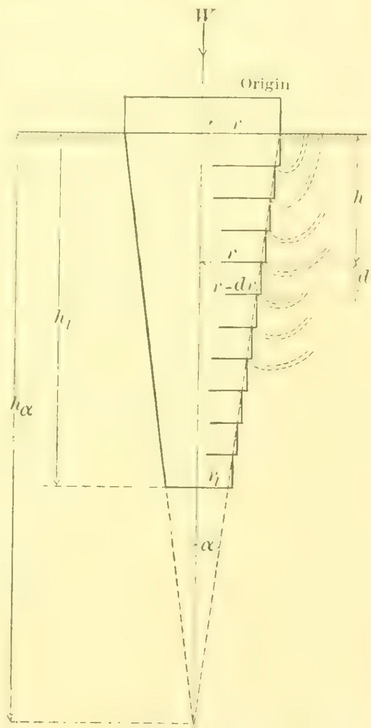

FIG. 1.

The dotted lines may be considered to represent displacement filaments passing out from the horizontal rims to the free surface around the head of the pile. The position of these lines can only be inferred from the treatises, say Ketchum's or Vierendeel's, as few if any precise investigations have been made along this line.

At incipient motion of the pile, it being assumed that it is at its final depth, any increment of the load will cause an actual displacement of the particles, and this will manifest itself as an increment or surface displacement to the upheaval surface which has formed around the head of the pile in driving. This assumption is necessary under the Rankine hypothesis of incompressible particles, although it has been the writer's experience that the phenomenon is often difficult to observe at such a stage. The load at this time is considered to be the ultimate carrying capacity, by the Rankine law.

The area of a small rim of variable radius, r, and width, $dr = 2\,\pi\,r\,dr$.

Let $p =$ the intensity of pressure on this rim element.

Then $p = wh\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2$ for a maximum,

where $w =$ the weight of a cubic unit of earth,

and $\phi =$ the angle of internal friction, assumed as constant.

The total pressure on the element $= 2\,\pi\,r\,dr\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2 wh.$

Now substitute $r = (h_a - h)\tan.\,\alpha$,

and $dr = -\tan.\,\alpha\,dh$,

where h_a represents the distance from the surface to the vertex of the cone formed by the surface of the pile, $h_l =$ the actual length in the earth, and $\alpha =$ the angle of slope of the conical surface. The total pressure on the rim element becomes

$$2\,\pi\,w\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2 \tan.^2\alpha \int_{h_l}^{o} -(h_a - h)\,h\,dh.$$

In order to take account of a principle of continuity, which in this case will manifest itself in the law of pressure varying as a function of the depth, one may conceive that, as the elementary rim pressure exceeds the amount above given, the pile will tend to subside under this, so that each rim will take its proportionate quota of stress in turn. The total buoyant effect is at the limit when the pulley-shaped foundation becomes a conical-shaped pile. The value of the integral becomes:

$$\int_{h_l}^{o} -(h_a - h)\,h\,dh = \left[-\left(h_a\frac{h^2}{2} - \frac{h^3}{3}\right)\right]_{h_l}^{o} = h_a\frac{h_l^2}{2} - \frac{h_l^3}{3},$$

and, substituting this in the previous expression,

$$P_{(lat.)} = 2\,\pi\,w\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2 \tan.^2\alpha\left[h_a\frac{h_l^2}{2} - \frac{h_l^3}{3}\right],$$

where the expression, $P_{(lat.)}$, represents the entire upward pressure on the lateral surface of the pile. To this must be added the basal pressure, giving, for the total load, P, which the pile can sustain according to Rankine's theory:

$$P = 2\,\pi\,w\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2 \tan.^2\alpha\left[h_a\frac{h_l^2}{2} - \frac{h_l^3}{3}\right] + \pi\,r_l^2\,wh_l\left(\frac{1 + \sin.\,\phi}{1 - \sin.\,\phi}\right)^2.$$

In the case of the "butt end down," the weight of the variable column of earth may be similarly summed and added to the load on the pile, and this equated to the bearing power of the base.

Such an analysis assumes, of course, that the earth conditions, absence of cohesion, etc., will warrant a treatment by the Rankine method. It is believed to give all that can consistently be demanded of the hypothesis.

Limitations of the Theory. It will be seen that the above application is quite limited in its efficiency as a working method. Specifically, it neglects the friction on the vertical projections of the face. Indeed, the Rankine premises do not take cognizance of any foreign body, such as the pile, but confine the problem to an indefinite extent of the material.

While it assumes the existence of displacement tubes, it makes no analytical provision as to their zone of action, unless one may take any series of vertical and horizontal lines as defining the field.

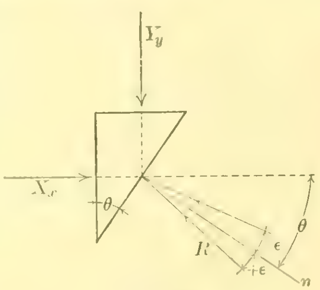

FIG. 2.

The usual applications of this theory assume a constant coefficient of friction, which, in the light of experiment, is only approximately tenable; but, confining the problem to its own more particular domain, the chief limitation is the necessity of the assumption of Moseley's law of least resistance as Rankine referred to it, at once either the element of weakness or of strength in his method, as one may prefer to call it.

Consider an ordinary wedge element of the material, Fig. 2, with vertical and horizontal faces and an inclined face the normal of which, n, is inclined at an angle, θ, with the horizontal. The area of this θ-face may be conveniently taken as unity.

Let the intensity of the vertical stress be considered in this particular case as due to a column of earth of length y feet below the surface of the ground, the value of which is Y_y. The corresponding intensities upon the x- and θ-planes, respectively, are X_x and R. The stress, R, has an obliquity of $\pm\ \epsilon$ from the normal. By compounding stresses, by any of the elementary methods, there results the general expression:

$$X_x = \frac{\tan.\ \theta}{\tan.\ (\theta \pm \varepsilon)} Y_y.$$

To evaluate X_x, another condition is required. Rankine sought to supply this condition through the Moseley assumption, taking the obliquity, $\pm\ \varepsilon$, as having its maximum value, ϕ, at impending motion of the particles. By seeking the maximum and minimum values of $\frac{\tan.\ \theta}{\tan.\ (\theta \pm \varepsilon)}$ on this basis, there results then, for the particular values of θ where Rankine's value of X_x may be assumed to hold:

$$\theta = \text{multiples of } \frac{\pi}{4} - \frac{\phi}{2}, \text{ for } X_x \text{ a maximum,}$$

$$\theta = \text{multiples of } \frac{3\ \pi}{4} - \frac{\phi}{2}, \text{ for } X_x \text{ a minimum,}$$

for positive values of ϕ, and in a similar manner when ϕ is negative. For example, taking a common value of $\phi = 30°$, one receives $X_x = \frac{1}{3}\ Y_y$ and $3\ Y_y$, as in the ordinary case. For the above given values of θ, Rankine's solution may be considered to hold, but for all other values the problem is absolutely indeterminate. The common practice of engineers, in applying this method as a general solution to problems of earthwork, is quite in keeping with that practice which seeks the deportment of a column within the elastic limit from tests to destruction.

Neither will the common defense, of the law being on the safe side, hold in all cases. For instance, it has already been pointed out by Boussinesq* that, in the case of a retaining wall when it is in its ordinary position of equilibrium, otherwise than at the time of incipient motion, as predicated by Rankine, although the particles are less forcibly retained, they nevertheless exert upon the structure a greater thrust than that given by Rankine.

A number of practical phases of this indeterminateness might be cited, showing the shortcomings of the method as a theoretical device. This is made apparent in the packing of balls. For example, a rather low angle of repose may be expected for fine shot if it is dropped from a short height, but had one the patience to arrange the shot particle by particle in a pyramidal array, according to the geometry of packing spheres, a much higher angle might be obtained

* "Essai théorique sur l'équilibre des massifs pulvérulents, comparé à celui de massifs solides, et sur la poussée des terres sans cohésion," (1876), p. 5.

for the slope of the pyramid, and this would be entirely independent of the condition of the balls, that is, whether rough or frictionless. Further, taking the old problem of the thousand 1-in. balls* packed in cubical array in a 10-in. cubical box, it is quite possible to conceive of an angle of repose of 90° if the sides of the box could be gently removed, although, of course, in such a case, the equilibrium would be very unstable. In the latter cases, the Moseley assumption would be quite justifiable. However, taking another extreme, say, the thrust of barrels on the walls of a warehouse, only the exigency of an occasional earthquake could render the application of the method theoretically permissible. The law is inoperative.

It is such limitations as have been cited that render the Rankine method of rather doubtful utility for any general rational treatment, either of the pile or the retaining wall. European and other than American authorities have ceased treating the Rankine formula as a general solution for all problems involving the lateral pressure of earth, and prefer to give it its more proper position as defining one particular kind of equilibrium. Even in its own special field, a solution approaching nearer the facts may doubtless be secured in many cases by the more determinate method of Greenhill,† as in the instance of barrel thrust.

Theoretical Position of the Method.—In order, then, to give to the Rankine theory applied to the pile that definiteness of position which attaches, say, to that of Euler's formula in the column theory, it may be defined as the theory of an infinitely smooth shaft afloat on a medium deporting in several respects as a sort of generalized fluid, where the particles are subject to negative normal stresses or pressures and to tangential or friction stresses, but where no permanent shearing resistance exists. In such a theory the vertical pressures may be assumed to follow the hydrostatic law. The horizontal pressures will also follow this law, but, owing to friction, the effect is such as would occur with a reduced specific weight, $w\left(\frac{1 \pm \sin. \phi}{1 \mp \sin. \phi}\right)$, where ϕ is the angle of internal friction, or, as Rankine referred to it usually, the angle of repose. The ($\pm$) signs are to be used in the above for the case of maximum loadings, in

* Quoted by Greenhill from "Cosmos," September, 1887, "Hydrostatics," p. 52.

† Greenhill's "Hydrostatics," pp. 45 *et seq.*

which case the pressure exerted by the pile is a so-called "active force," as the term is used by Rankine. The (∓) signs are for minimum loads on the pile, namely, if the "buoyancy" of the surrounding earth (viewing this now as an active force) is greater than the load on the pile, as prescribed by this theory, the pile will tend to rise, and may actually do so, especially if the medium contains more or less water.

Accordingly, it will be seen that the laws of pulverulent masses will agree well with the theory originally advanced by Boussinesq,* and given later by Flamant,† Greenhill,‡ and others, in that they are intermediate in their properties between fluids and solids. Fresh cement, in its ordinary condition, will follow closely the hydrostatic law, but, under pressure, will take on the properties of elastic bodies. Even the Rankine equations, if consistently interpreted, find analogies in the theory of stress and strain in solids on the one hand (Tresca), and agree with the hydrostatic law for $\phi = 0$, on the other.

A dynamics of pulverulence is quite possible to formulate under such a notion, and would probably find practical applications in designing orifices for the discharge of grain, etc. Under this caption such phenomena as have been described by Vierendeel§ as occurring at the circumference of disk piles, and by Le Conte‖ and Goodrich,¶ as "cones" and the like, forming under the bases of models, would probably find interpretation as suppressed vortex or eddy effects.

Practical Utility of the Rankine Formula.—While the Rankine theory is little more than an abstraction, and if consistently and rationally applied to a single pile can only be expected to give a fraction of the real carrying power, its utility to the practicing engineer may still exist in the fact that a multiple-pile system may be tested by Rankine's equations about as logically as they may be applied to any ordinary foundation. In such a multiple pile the integrity of the structure is usually preserved by suitable framing; but, if this were not so, the material in the cusp-like interstices between the piles can be expected to be much more compressed, and consequently to have a considerably

* "History of the Elasticity and Strength of Materials," Vol. II, Pt. II, Article on Boussinesq, by Karl Pearson.

† "Stabilité des Constructions," p. 111.

‡ "Hydrostatics," pp. 45 *et seq.*

§ "Cours de Stabilité des Constructions," Vol. VI, p. 246.

‖ *Transactions*, Am. Soc. C. E., Vol. XLII, p. 284.

¶ *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 181.

higher friction factor, than the less restrained material at the periphery of the composite structure, thus tending to maintain this unity of action.

In a multiple pile great reliance is placed on the increased density of the soil, due to the driving, with the corresponding increase in the friction coefficient. As the condensation under the Rankine premises is purely inelastic, an approximate idea of the increase in density may be found by an equation between the displacement of the pile and the upheaval mass around the head.

Nearly all writers, with the exception of Vierendeel, in discussing the bearing power of foundations, follow Rankine in ignoring the stresses on the side walls, and confine their analysis solely to the base. Accordingly, on the common theory, a designer of a multiple pile would neglect the peripheral friction on the composite structure in comparison with the presumably larger pressure on the base. In this case such a procedure can be viewed as giving only crudely approximate results. It is believed that the phenomenon of dilatancy of media composed of rigid particles, as studied by Professor Osborne Reynolds,* may even warrant the belief that this lateral friction is larger than supposed, especially in water-bearing strata. The writer will revert to this point later.

The Elastic Theory.—Nearly all the structural problems of engineering find their ultimate analysis in the elastic hypothesis. This is true of the arch, and in a large measure of the retaining wall. Just as the beam, on account of the labors of de St. Venant and his contemporaries, owes its truly rational position to such elastic studies, quite independent of the empiricists, the column theory, with of course a few possible exceptions, may be said to have made no consistent advances since the days of Euler by departing therefrom.

While to place such an apparently crude and sordid problem as the pile in this field will undoubtedly seem inopportune, it is believed that, in the end, such a step will avoid a great deal of useless effort and incorrect thinking. It is thought important to bring out a few arguments *pro* and *con* as to the advisability of such procedure.

In the first place, to make the problem of the lateral pressure of earth truly determinate, the idea of strain is involved. Its introduc-

* *Philosophical Magazine* (London, E., and D.), Vol. XX, 1885, p. 469. "On the Dilatancy of Media Composed of Rigid Particles in Contact;" also Reynolds' Works, Vol. III.

tion into the analysis is due to Boussinesq. Take the case previously cited, of the problem of the balls packed in the 10-in. box in cubical array. The problem of their lateral pressure against the walls owing to their own weight becomes at least theoretically determinate, provided all the stress and strain constituents of the material are known, and the elastic deportment of the walls is understood. Although such elastic solutions are in many cases extremely difficult to obtain, on the other hand, they have the advantage of a high degree of certainty of result, and will tend to obviate that endless modification so common, say, in column and pile formulas.

As contributing data toward such a final and correct analysis, ideal problems, approximating in part toward the actual conditions, may be solved. For example, it may be shown that:

"If a vertical cylindrical hole of circular section is cut in a rigid body, and an elastic cylinder of density ρ, which, if freed from the action of gravity, would exactly fit the hole, is placed in it and stands upon the bottom, * * * the sides of the hole suffer the same hydrostatic pressure as if it were filled with a liquid of density $\rho\ (m - n)\ (m + n)$." (Ibbetson.)

Slichter,* in commenting along this line, remarks:

"It is important * * * that we should have before us the solution of as many problems as possible, since the most likely method by which we shall be able to solve a new problem is by reducing it to one of the cases in which a similar problem has been constructed by the inverse process. Indeed, one must often be content to secure an approximate solution in a given case by searching among problems already solved for one whose equipotential lines or surfaces have a form somewhat resembling the given boundary, and then so to modify the problem by tentative methods as to produce conditions more nearly corresponding to those of the given problem. For this reason it is desirable to solve all possible kinds of problems * * * whether they seem to be 'practical' or not."

Accordingly, Coulomb, Rankine, Weyrauch, Levy, Boussinesq, Kötter, and others, have contributed much in their study of various kinds of equilibrium. The work of Boussinesq, while furnishing valuable researches in the whole field, seems to be carefully ignored by the practicing profession.

Such an elastic hypothesis, it has been urged, is less applicable to

* "Theoretical Investigation of the Motion of Ground-Waters," by C. S. Slichter (Government Printing Office, Washington, D. C., 1899), p. 333.

the case of earth pressure than in the case of any other medium, it being difficult to predicate continuity laws of the medium and the existence of derivatives, as is done in hydrodynamic and elastic theories. As sufficiently typical of such criticism, the remarks of Darwin* are closely to the point.

"It has always been assumed by previous writers that the tangential action across an ideal interface in a mass of loose earth is of the same nature as the statical friction between solids, and that when the tangential stress has attained in magnitude a certain fraction of the normal stress, the equilibrium is on the point of breaking down. * * * A little consideration will show that the hypothesis cannot be exact, even with an ideal sand with incompressible grains, and absolutely devoid of coherence. For imagine a mass of sand thrown loosely together; then if the grains are of irregular shape a certain portion of them will be resting on points and angles, thus occupying more space than they might do.

"If the sand be now compressed, many of the grains will slip and rotate, and fall into interstices; in fact a considerable amount of re-arrangement will take place, and the density of the mass will rise considerably—by quite 10 per cent. if the re-arrangement be thorough, as found experimentally.

"Even if all the grains were spherical a considerable amount of change would take place, and when they are angular of course much more. * * *

"Hence it is clear that the coefficient of internal friction of sand is a function of the pressure, and not merely of the pressure then existing, but also of the pressure and shaking to which at some previous period that portion of the mass of sand has been subjected. * * *

"It is quite impossible to say how much these causes will vitiate any mathematical theory of the equilibrium of sand, but experience seems to show that the vitiation is extensive."

On the other hand, in the elastic theory, the researches of Boussinesq† show that pulverulent material when under presure—such as may occur in this particular case of the pile owing to impacted soil through driving, even more than in the retaining wall—resists a change of form with a force which is proportional to the mean of the three principal stresses acting on the particle. He takes the coefficient of rigidity, μ, as varying with this mean pressure. As the weight on the particle increases, either owing to its own "head," or, in this case, to

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* *Minutes of Proceedings*, Inst. C. E., Vol. LXXI, 1883, "On the Horizontal Thrust of a Mass of Sand," pp. 374 *et seq.*

† "Essai theorique * * *," p. 6.

the compressed soil in driving, the surrounding medium approaches an elastic body in its properties. Under great pressure, of course, it becomes perfectly so, thus justifying geologists or physicists in calculating earth stresses, delta pressures, faults, etc., by known elastic methods.

Now, the writer believes that there is a tacit notion, prevalent among representative engineers, which is quite conformable to such an hypothesis, and in support of this belief would quote the remarks of Goodrich:*

"When a pile is supported entirely by the frictional resistance, the actual region supporting the load is some deep ground level at which the frictional resistance holding the pile has been transferred through the earth in the shape of a conoid of pressure, the base of which gives a total bearing value equal to the load and a unit bearing value which the earth at that lower level will support. Each kind and degree of compactness of earth will give a different angle for the slope of the conoidal surface."

Again, he says:

"When supported by frictional resistance, they [the piles] must be driven so far apart, or to such a depth, that the increased area of bearing developed by the conoid of pressure having the required altitude of frictional resistance meets a level which will afford the required support before intersecting the conoid of a neighboring pile."

Such a description would seem to show analogies with the "fan" distribution of Stokes and Carus Wilson,† with the local perturbations of Boussinesq,† or some of the equipollent effects of de St. Venant.

It is natural to ask, however, how the inelastic distortions of Darwin can be made to harmonize with the other views. The answer would be by postulating or defining the medium. Slichter,‡ in a somewhat related problem involving a study of the flow of groundwaters through a soil, has attacked his problem very successfully by the assumption of a mean soil. The size of the grains in a soil having the same transmission power as the more complex soil he calls the "effective" size. He says:

"There probably exists a tendency in every such soil toward a certain average size and mean arrangement of grains which the theory

* *Transactions*, Am. Soc. C. E., Vol. XLVIII, "Supporting Power of Piles," pp. 182 *et seq.*

† *Proceedings*, Physical Society of London, Vol. XI, 1891, p. 194, "The Influence of Surface-Loading on the Flexure of Beams."

‡ "Theoretical Investigation of the Motion of Ground-Waters," p. 305.

of probabilities would justify us in setting up as an ideal soil to replace a given soil in the investigation."

The same remarks may be applied to the analysis of the pile and related phenomena. It is this idealization of the problem which is tacitly done in all the problems of engineering, perhaps, however, with less justification at this time in the theory of earth pressure, on account of the lack of physical investigation.

On the whole, the opinion of elasticians, Darwin and de St. Venant included, would seem to be favorable to an elastic analysis of the problem of the lateral pressure of earth and pulverulent material. Pearson,* in his critique of the elastic analysis of Boussinesq, has said:

"They appear to contain the most complete scientific theory yet given of the stability of such a mass * * * indeed, they are perhaps the limit to what elastic theory can provide in these directions."

In view of the dearth of knowledge of strain and friction factors, little progress can be made. It is believed, however, that as engineers direct their attention to the static outlook and conduct experiments along this line, a great many features now rather obscure will clear up. Such a study also affords another angle of vision upon the pile viewed dynamically and the retaining wall.

General Notions.—For purposes of discussion, consider a pile driven or jetted to place and carrying, say, its maximum load. It is desired to investigate the mechanical state of the soil as it reacts upon the pile and prevents its further subsidence under the load. The principles of mechanics† furnish the following well-known equations for the static equilibrium of a volume element of the material surrounding the pile, say, a small parallelopiped the co-ordinates of which, as shown in Fig. 3, are x, y, and z.

$$\frac{\delta X_x}{\delta x} + \frac{\delta X_y}{\delta y} + \frac{\delta X_z}{\delta z} + \rho X = 0$$

$$\frac{\delta Y_x}{\delta x} + \frac{\delta Y_y}{\delta y} + \frac{\delta Y_z}{\delta z} + \rho Y = 0$$

$$\frac{\delta Z_x}{\delta x} + \frac{\delta Z_y}{\delta y} + \frac{\delta Z_z}{\delta z} + \rho Z = 0$$

Using the Kirchoff notation, as preferable to that of Lamé, the expression, X_x, represents the intensity of normal stress on the elementary area, $dy\ dz$, of the parallelopiped, that is, the stress acting

* "History of Elasticity and Strength of Materials," Vol. II, Pt. II, pp. 313 and 357.

† "Theory of Elasticity," by Love, Chapter V, pp. 122 *et seq.*

in the direction of the x-axis upon the plane element, $dy\ dz$, perpendicular to this plane. Briefly, X_x represents the x-stress upon the x-plane. In a similar manner, X_y is the x-stress on the y-plane, a shearing or tangential stress; Z_z is a normal stress upon the z-plane, and so on. Since the shears at right angles are always equal, then $Y_x = X_y$, $Z_x = X_z$, $Z_y = Y_z$; but, for convenience of mental retention, the symmetrical notation commends itself. The equivalence can be asserted as desired in calculations of any particular problem.

The expressions, ρX, ρY, and ρZ, where ρ is the density, represent "body forces," such as gravity or "centrifugal" force. In this case, these volumetric forces may be the components of gravity in the direction of the co-ordinate axes, or, as these are taken in Fig. 3, $\rho X = \rho Z = 0$, and $\rho Y =$ the weight of the earth per cubic foot in the engineer's notation. For sand charged with water, this would be, say, 110 lb., or as the case might be.

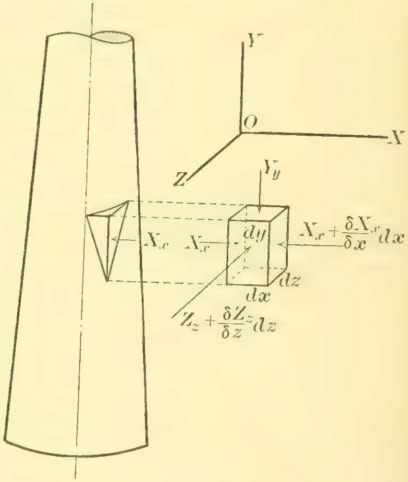

Fig. 3.

The foregoing equations, as used by Rankine* in his original paper, are rigid body equations. Boussinesq,† by introducing a comprehensive theory of strain, formulates an independent system for the theory of earth pressure. There are, of course, relations of compatibility in the general problem which will show analytically, as already shown for the Patton equations, that the engineer cannot choose his values at random.

Thus far, as the writer has discovered, few practical data in the matter of strain are accessible for different earths. Reference to this must be brief. The theory, then, will be founded on stress relations, as in the ordinary beam formula, for practical purposes.

In the case of conical or cylindrical piles, the equations for static equilibrium in a final analysis will be best expressed in the well-

* *Philosophical Transactions*, Royal Society, 1857.

† "Essai théorique sur l'equilibre d'elasticité des massifs pulvérulents * * *," p. 24, etc.

known cylindrical co-ordinates, the notation being similar to that used before, namely:

$$\frac{\delta Y_y}{\delta y} + \frac{\delta Y_r}{\delta r} + \frac{\delta Y_\phi}{r\, d\phi} + \frac{Y_r}{r} + \rho\, Y = 0$$

$$\frac{\delta R_y}{\delta y} + \frac{\delta R_r}{\delta r} + \frac{\delta R_\phi}{r\, d\phi} + \frac{R_r - \phi_\phi}{r} + \rho\, R = 0$$

$$\frac{\delta \phi_y}{\delta y} + \frac{\delta \phi_r}{\delta r} + \frac{\delta \phi_\phi}{r\, d\phi} + \frac{\phi_r + R_\phi}{r} + \rho\, \phi = 0$$

In these equations the capital letters give the direction of action of the stress and the subscripts refer to the planes on which they act. For example, ϕ_y represents the intensity in the direction of the normal to the plane, $dr\ dy$, on the y-plane, that is, the plane, $dr\ r\ d\phi$, etc. The shears in rectangular directions, as in the previous case, are equal.

In this more complicated case, however, owing to the symmetry about the y-axis, or axis of the pile, the "hoop compression" becomes constant around any particular ring element of the radius, r. The shears also vanish on the ϕ-planes, that is, any of the faces, dy, dr. This distribution of stresses, when a solution of the various particular intensities is obtained, may ultimately be used for obtaining the tubes of stress, their intensities and slopes at any point, in the conoid described by Goodrich.

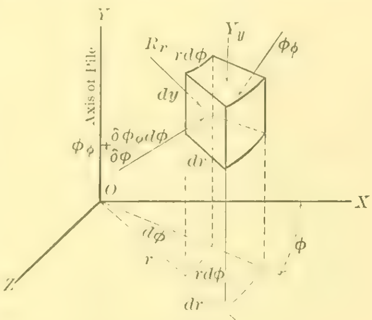

FIG. 4.

Now, to make any particular problem a determinate one, such types of equilibrium equations as have been given are to be satisfied for all values of the variables and for certain boundary conditions, namely, at the upheaval surface and at the entire periphery of the pile. In a continuous beam the analogy exists in the state at the supports. Similarly, a correct column formula must not only satisfy such equilibrium equations along the axis, but also hold for very long and very short columns. The problem under discussion is relatively more determinate than in the column problem, as the best that may ultimately be expected in the latter case is a least-square solution.

At the surface of the pile the following type of equations must be satisfied, as well as for the upper surface.*

* "Theory of Elasticity," by Love, Chapter V, pp. 122 *et seq.*

$$X_n = X_x \cos. (x\,n) + X_y \cos. (y\,n) + X_z \cos. (z\,n)$$
$$Y_n = Y_x \cos. (x\,n) + Y_y \cos. (y\,n) + Y_z \cos. (z\,n)$$
$$Z_n = Z_x \cos. (x\,n) + Z_y \cos. (y\,n) + Z_z \cos. (z\,n)$$

To make these expressions clear, it may be remarked that the surface of the pile, being in the general case the surface of a cone, will transform the volume element of earth, $dx\ dy\ dz$ (Fig. 3), into a tetrahedral element. And these equations assert the equilibrium of all stresses on the tetrahedron in the directions, x, y, and z, respectively.

Call the surface element of the pile, that is, the inclined face of the tetrahedron element, the n-face, because its normal is, say, n. Let its area be unity, for convenience of discussion. Then the other faces, namely, the x, y, and z-faces, respectively, are cos. (xn), cos. (yn), and cos. (zn), where (xn), (yn), and (zn) are the angles between the x, y, and z-directions and the normal of the n-face or n. Accordingly, X_n is the resultant stress component in the x-direction on the surface element of the pile. A similar set holds for the ground surface, but becomes very much simpler owing to vanishing of terms when the upheaval surface is assumed as horizontal.

Now, in a precise and finished analysis involving the strain relations, both the boundary equations just given and the equilibrium equations are usually expressed in terms of these strains. Just as they are neglected in the derivation of the beam formula, they will be neglected here. The two sets of equations will be used solely as stress relations, as given, to keep the problem within working bounds.

A two-dimensional solution only can be attempted at this time, on account of the analytical difficulties involved in the more general treatment. It is believed, however, that a general solution exists in the case where the "immersed" length of pile is zero in the Boussinesq* problem of the distribution of stress and strain due to a rigid cylinder resting upon an infinite elastic solid, combined, of course, with suitable superpositions to provide for the weight of the soil. Moreover, since the strain in the earth at some distance from the body is quite independent of the manner of distribution of the peripheral stresses, but will depend rather on the resultant statically

* "Application des potentiels à l'étude de l'équilibre et du mouvement des solides élastiques," 1885.
"History of Theory of Elasticity," Todhunter-Pierson, Vol. II, Pt. II, p. 237.
Love's "Theory of Elasticity," Chapter VIII.

equivalent to them, it is thought that this solution for immersion of length zero may actually be taken for finite lengths of the pile. It would seem to the writer that the existence of the "cone" under the base will approximately justify this.

All authors, from Barlow and Rankine to the present time, have pleaded a lack of experimental data with which to correlate their mathematical investigations. The writer has felt this constraint in his attempts to get any trustworthy results from the case given, after analyzing the problem from different points of view; but, while these efforts have been largely fruitless, they have afforded certain lines of approach in analyzing the "conoid."

One of these is that, in the case of experiment, instead of restricting the investigation solely to the special case of granular or pulverulent media, as all engineers have heretofore done, the problem should be generalized to include media which have elastic properties within limits, say clay, hardpan, spongy soils, and very probably sand in its most compact position, especially when it is charged with water. It is believed that, eventually, when more experiments have been made, these premises will be easier to work to than in the case of granular media. In some preliminary experiments along this line, made for the purpose of throwing light upon more precise efforts to be undertaken, C. J. Green, Jun. Am. Soc. C. E., and the writer used rather fine and compacted saw-dust, in a duplication of the Goodrich* experiment made with sand. Such a saw-dust medium will permit a considerable magnification of the strain that may be expected in an actual case, when a small vertical motion of the model pile is made in the medium, keeping the "pile" close to the glass wall of the box. Leygue,† in his experiments on retaining walls, used a series of strata of a different colored medium to bring out the faults in the sand and confirm his notion of a curved surface for the interior face of the Coulomb wedge. In like manner, this notion has been tried by "sprinkling" a series of co-ordinate lines of any convenient medium on the face of the glass wall when laid flat with the "pile" in place, and laying over this the saw-dust, with a view of showing the strained lines when a small vertical displacement of the "pile"

* *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 181.

† *Annales des Ponts et Chaussées*, 1885.

occurs. The original positions of the co-ordinates are marked on the glass with a wax pencil.

Two limiting aspects are to be studied: First, the strained condition for a very smooth or polished prism with a flat base, and then that for one with serrated or notched faces next to the saw-dust. The first case simulates that where the pressure on the sides is normal. The second case approximates the actual status of a pile in a cohesive soil where the full friction exists. While little of this has been carried out, it is believed that qualitative data of value will be obtained by using, not only straight prisms, but also wedges of rectangular cross-section with the faces next the material inclined to and from the vertical. It is hoped in the first case to obtain the deportment of the material under the pile. Preliminary experiments seem to confirm, partially at least, such a flow of stress as has been already derived both experimentally and analytically by Hertz* in the well-known problem of the pressure between two elastic bodies in contact. It is thought, by carrying out the Goodrich experiment as thus described, not only for sand, but also for other "more springy" media, that a great deal of light may be afforded, not only on the basal action of the pile, but also on the related problems of surface loading, as in beams, etc. Here, analysis is already far ahead of experiment, at least for elastic bodies.

In the second case, it is desired to discover the zone of action in regard to the lateral friction in a cohesive and elastic soil. In the subsequent analysis this can only be assumed for the case of pulverulent material.

Two-Dimensional Stress Relations.—With the Rankine premises the uniplanar or two-dimensional case is easily extended to three dimensions by the assumption of a vertical axis of symmetry, namely, his ellipse of stress relation becomes an ellipsoid of stress; but, when the influence of a body such as the pile is concerned, the problem becomes greatly complicated, involving a solution in the case of stress alone of the equations of equilibrium in cylindrical co-ordinates subject to proper boundaries, as has been shown. The writer has been unable to obtain general solutions for these, as has been already remarked.

*Hertz, "Miscellaneous Papers," Translation by Jones and Schott.
Hertz, J. F. Math. (Crelle), Bd. 92 (1881).
Love's "Theory of Elasticity," p. 195.

It is proposed, in accordance with the suggestion of Slichter, to attempt an approximate solution as the best available at this time. Such a solution, accordingly, may be considered to be a second approximation to that already given by Patton and by Desmond, but it will avoid largely the Rankine inconsistencies. This may then be used in studying the experimental data at hand with a view to discovering the general law, if such law does not already exist, at least for short piles in the Boussinesq problem of the rigid cylinder.*

In a two-dimensional case, either of the sets of equilibrium equations may be applied as it were to a pile of very large radius, or, taking as equivalent, a stretch of sheet-piling. Accordingly, the piling partakes more or less of the nature of the retaining wall.

Two-dimensional treatments of the equilibrium equations have already been given, in the case of the retaining wall, by Kötter† and Boussinesq. As the latter has discussed local effects particularly, it is believed his results may be applied to the pile.‡

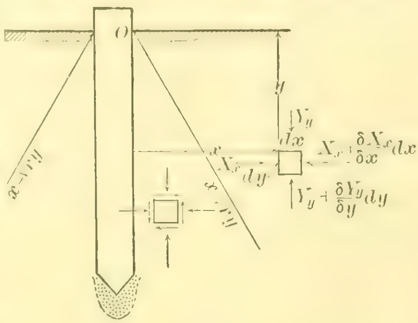

FIG. 5.

The equilibrium equations, being independent of z, or the direction in the length of the wall or piling, reduce to

$$\frac{\delta X_x}{\delta x} + \frac{\delta X_y}{\delta y} = 0 \quad \text{for the } x\text{-direction,}$$

$$\frac{\delta Y_x}{\delta x} + \frac{\delta Y_y}{\delta y} + (\rho g = w) = 0 \quad \text{for the } y\text{-direction.}$$

The region of perturbation is supposed to extend to the line the equation of which is

$$x = \sqrt{\frac{1 - \sin.\ \phi}{1 + \sin.\ \phi}}\ y = \sqrt{r}\ y,$$

where the coefficient $\sqrt{r}$, is the square root of the Rankine ratio. This must here be tentatively assumed. (See Fig. 5.)

* "Application des potentiels à l'étude de l'équilibre et du mouvement des solides élastiques," 1885 (Gauthier-Villars, Paris).

† "Erddrucken auf Stützmauern," Müller-Breslau (Stuttgart, 1906), pp. 107 *et seq.*

‡ *Annales des Ponts et Chaussées*, T. III, pp. 625-643.
See also "Theory of Elasticity," Todhunter-Pierson, Vol. II, Pt. II, p. 347; and *Minutes of Proceedings*, Inst. C. E., Vol. LXV, p. 212.

The general Rankine relation is assumed to hold outside of this region at a distance from the pile, namely,

$$\sin.^2 \phi = \frac{(X_x - Y_y)^2 + 4 X_y}{(X_x + Y_y)^2},$$

which states the expression for the "stability of a mass of earth in terms of the pressure at a point referred to any pair of rectangular axes, OX' and OY', in the plane of greatest and least pressure."* Taking $4 X_y = 0$, the common expression is easily derived.

As a justification of the use of the above, it is assumed here that the plunger and cylinder experiments of Goodrich give a fair confirmation. (Whether $\frac{1}{5000}$ in. $\pm$ movement of the "plug" will permit the inference that the pressure on the plug is of the same intensity as that on the walls of the cylinder has always raised a query in the writer's mind.†)

Since the weight at the surface, assumed flat, is zero, the boundary relations become, by the vanishing of terms in the equations for the tetrahedron:

$$Y = 0, \qquad Y_x = X_y = 0.$$

At the sheet-piling (the retaining wall in the problem of Boussinesq), there results $X_y = \tan.\ \phi_1\ X_x$, where $\tan.\ \phi_1$ is the tangent of the angle of obliquity of the resultant pressure on the vertical face at the pile.

Boussinesq assumes "that in practice sustaining walls are generally sufficiently rough to render a thin stratum of the pulverulent mass stationary upon them. Hence the angle of friction between wall and mass really reduces to the angle of friction of the pulverulent mass upon itself."‡ This certainly is the maximum value. Kötter differentiates, however, the obliquity upon the x-face from that on the θ-face. In the case of sand, on account of dilatancy, the writer will follow the Boussinesq assumption, but for soils not granular or pulverulent will obtain such values for the later numerical computations as may be had from actual tests. Cain, Darwin, and others follow Boussinesq in retaining-wall design in this respect.

* *Philosophical Transactions*, Royal Society, Vol. 147, p. 18.

† *Transactions*, Am. Soc. C. E., Vol. LIII, p. 283.

‡ "History of Elasticity," Todhunter-Pierson, Vol. II, Pt. II, p. 336.

The following solution is given for the equations of equilibrium:

$$X_x = \frac{1 - \sin.\ \phi}{1 + \sin.\ \phi}\, w\, y,$$

$$X_y = 0,$$

$$Y_y = -w\, y,$$

to apply without the region limited by $x = \sqrt{\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}}\, y$, and these are the ordinary Rankine relations. Within this region, or in the zone of perturbation of the pile, the following equations hold:

$$X_x = \frac{1 - \sin.\ \phi}{1 + \sin.\ \phi} \cdot \frac{(y + x \tan.\ \phi)\, w}{1 + \sqrt{\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}} \tan.\ \phi}$$

$$Y_y = -\frac{(y + x \tan.\ \phi)\, w}{1 + \sqrt{\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}} \tan.\ \phi}$$

$$Y_x = X_y = -\frac{\tan.\ \phi \sqrt{\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}} \left(\sqrt{\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}}\, y - x\right) w}{1 + \sqrt{\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}} \tan.\ \phi}.$$

In the above set of constituents, the stresses, X_x and $Y_x = X_y$, are induced stresses, that is, they are called into play on a hypothetical infinitesimal motion outward of a retaining wall by the pressure head, Y_y. In the Rankine language, they stand to each other in the relation of "cause to effect." The pressure head of earth is "active," and the induced lateral stress is "passive."

In the case of piling, however, Y_x is the "active" stress. Accordingly, one would assume, very consistently, that the resultant stress on the x-face of a small element at the piling is active. To provide for this case, one might proceed in the ordinary manner of Rankine, namely, take $X_x \left(\dfrac{1 - \sin.\ \phi}{1 + \sin.\ \phi}\right)^2 = Y_y$. This would appear to introduce ambiguities into the problem. The writer will proceed as follows:

Call the passive or smaller ratio of Rankine r_p and the active or larger ratio r_a. If Y_x and X_x are active, it seems reasonable to assume that the zone of perturbation due to pile action is larger. The wedge defining this region, the slant height of which is $x = \sqrt{r}\, y$, must intersect the head of the pile at the ground, because, whether

"active" or "passive," the shears vanish at the pile for $y = 0$. Let $x = \frac{1}{\sqrt{r_p}} \cdot y = \sqrt{r_a}\, y$. The following is still true: At any point without the region the general Rankine relations hold. The constituents hold in general for all values of the variable within the region; the intensities become zero at the surface; while, at the pile, for $\phi = 0$, the ordinary Rankine relations still hold, the more general relations hold for ϕ_1.

To obtain a direct application of this, it is necessary to integrate the intensity, Y_x, over the surface of the pile at $x = 0$. First call

$$Y_{x0} = \tan.\ \phi_1 \frac{1 + \sin.\ \phi}{1 - \sin.\ \phi} \frac{w\, y}{1 + \sqrt{\frac{1 + \sin.\ \phi}{1 - \sin.\ \phi}} \tan.\ \phi_1} = \frac{f\, r_a}{1 + f \sqrt{r_a}}\, w\, y$$

for simplicity of expression, where f = the coefficient of friction at the pile, w = the specific weight of the earth, and y = the variable depth. To apply this intensity in practice, where cylindrical and slightly tapering piles are used, the assumption of Vierendeel and the others is made, that the tangential intensity is independent of the shape of the perimeter of the pile, a common enough assumption in other branches of engineering.

By integration there results for a working formula comparable with the Sanders' type in simplicity, but based on static considerations:

$$W = \frac{f\, r_a}{1 + f \sqrt{r_a}}\, w\, \pi\, D \int_o^L y\, dy,$$

$$\text{or } W = \frac{f\, r_a}{1 + f \sqrt{r_a}}\, w\, \pi\, D \frac{L^2}{2},$$

where $\pi\, D$ is the mean circumference, L is the length of pile, w is the weight of a cubic unit of earth, f is the coefficient of friction, and r_a is the larger Rankine ratio, namely, $\frac{1 + \sin.\ \phi}{1 - \sin.\ \phi}$, ϕ being the angle of internal friction, or so-called angle of repose.

Now $w\, \pi\, D \frac{L^2}{2}$ is the normal hydrostatic pressure on a cylinder for w = specific weight. Accordingly, $\frac{f\, r_a}{1 + f \sqrt{r_a}}$ is a more or less rational friction factor for the same. While the formula is quite

as simple as Vierendeel's, it would seem to possess a more rational derivation.

Effect of the Base.—In the above working formula, upward pressure on the base and sides, other than that due to tangential stresses, has been disregarded as relatively negligible. This will need to be discussed.

First, in the case of stiff earths possesssing some elastic properties, where a more or less well defined "conoid of pressure" may be assumed to exist, the pressure over the base of this conoid is naturally assumed to be continuous. The principle of equipollent loads (de St. Venant) shows that it is only in the region of the point that the real distribution of stress has any effect. In the case of a peg driven into a wooden beam and carrying a load on its head acting longitudinally to the axis of the peg, the local effect of the stress would be much the same whether the point of the peg entered a small knot-hole or butted against sound wood. The assumption, then, will be that the pressure under the pile is practically that which exists a foot or two horizontally away. In the horizontal projection of the lateral surface, the Y_y is assumed to be that for $x = 0$, $y = y_1$.

In the case of the Goodrich experiment, with the box and glass walls, when the model pile is pushed down in the sand close to the glass face the inverted paraboloid forming under the squared end of the pile is only two or three end diameters of the pile in height. The "eddy" action is largely confined to this small region. The Rankine hypothesis, of necessity, assumes that the action is felt at the surface, by reason of incompressible molecules arranged in most compact space. It is believed, however, as has been shown by Bauschinger, Darwin, and others, that considerable interstitial free space exists in any pulverulent soil; accordingly, when the pressure occurs it simply compacts the soil in the immediate region concerned. The assumption, then, for semi-liquid materials, it would seem to be reasonable, may be similar to that of the previous paragraph, namely, that the pressure at the point and sides suffers no sudden breaks or discontinuities from that a short distance away.

Accordingly, it is thought that the base and lateral buoyancy, when the point is down, may be amply provided for by taking L a few diameters longer, say to the point of the inverted paraboloid, instead of to the point of the pile, and using this length with the

mean diameter of the pile. Such data, of course, would need to be determined experimentally; or, perhaps it might be better to consider the friction factor, $\frac{f\, r_a}{1 + f \sqrt{r_a}}$, simply as an empirical parameter to be determined for various cases.

Some Data.—In lieu of any precise coefficients of friction and angles of friction, no great precision can be expected in fitting the formula to actual cases. In the following the formula has been applied to the Annapolis* tests, J. P. Carlin, Assoc. M. Am. Soc. C. E., Engineer in Charge, also to the well-known Louisiana† pile (Proctorville, La., 1856-57).

TABLE 1.—ANNAPOLIS TESTS.

Number.	Length.	Point.	Butt.	Hammer.	Fall.	Actual test load.	Formula.	Goodrich $\frac{10\, W\, H}{3\, p}$	Remarks.
1	91	7	22	2 300	22	75 000	105 200	96 500	$L =$ {60 ft. mud, 6 ft. sand} = 66 ft.
2	91	7	22	"	22	85 090	133 610	112 000	$L =$ {60 ft. mud, 12 ft. sand} = 72 ft.
3	73	9	18	"	33½	34 000	95 450	67 000	$L =$ 61 ft. of mud.
4	30	12	8	"	22	38 000	54 400	84 500	Sand.
5	32	13	9	"	22	110 000	66 500	168 700	Sand.

For Cases 1, 2, and 3, $f = 0.1$ and $\phi = 15°$ was used, for Cases 4 and 5, $f = 0.268 = \tan. \phi$, and $\phi = 15°$.

(See Patton's "Civil Engineering," 1st ed., p. 487, for actual test for f in liquid mud.)

w is taken at 110 lb. per cu. ft.

Case 1 is worked out below in full, to show the effect of vertical pressure on the side and base. The developed surface of contact is a trapezoid. The projected area on a horizontal plane is 1.45 sq. ft. The area of the base is 0.267 sq. ft.

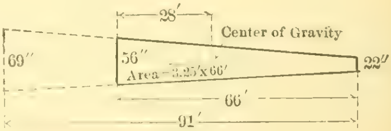

FIG. 6.

$$\frac{1 + \sin. 15°}{1 - \sin. 15°} = \frac{1.259}{0.741} = 1.70$$

$$\sqrt{1.70} \times 0.1 = 0.131$$

* *The Engineering Record*, May 11th, 1901; Also *Transactions*, Am. Soc. C. E., Vol. XLVIII, pp. 215 and 218.

† Baker's "Masonry," 8th ed., p. 247.

$$\frac{0.1 \times 1.70}{1.131} \times 110 \times 3.25 \times 66 \times 28 = \quad 99\,500, \text{ friction on side,}$$

$$\frac{66}{1.131} \times 110 \times 0.267 = \quad 1\,700, \text{ pressure on base,}$$

$$\frac{28}{1.131} \times 110 \times 1.46 = \quad 4\,000, \text{ pressure on projected face,}$$

$$W = 105\,200, \text{ total calculated load.}$$

The common hydrostatic methods of area multiplied by mean head is used instead of the integration. The Rankine pressure on the base and projected side is 5 600 and 13 000 lb., respectively, for $\phi = 15$ degrees.*

For the Louisiana case, Baker's "Masonry" gives the following data: Pile was 12 in. square throughout, driven 29.5 ft., and bore 29.9 tons without settlement. It settled slowly under 31.2 tons. The same values of f and ϕ are used as in Cases 4 and 5 of the Annapolis test, namely, $f = 0.268$ and $\phi = 15°$, or

$$\frac{0.268 \times 1.70}{1 \times \sqrt{1.70} \times 0.268} \times 110 \times 4 \times \frac{29.5^2}{2} = 64\,800, \text{ friction on sides,}$$

$$\frac{29.5}{1 \times \sqrt{1.70} \times 0.268} \times 110 \times 1.0^2 \quad = \quad 2\,320, \text{ pressure on base,}$$

$$W = 67\,120, \text{ total calculated load.}$$

The static treatment presented gives an average deviation from fact about commensurate with that of the most rational dynamic formula. It is thought, however, that by obtaining actual experimental factors, based on the physical qualities of the pile, a much closer agreement would be possible. Most of the recorded data, being made solely with reference to their availability for comparison and study of dynamic formulas, omit such information.

The formula presented, being of the form of that given by Vierendeel, who neglects the basal action, it should be easy, by drawing tests, to acertain the friction, expressed as a function of length and mean diameter, for different soils.

Dilatancy of Granular Media.—In his interesting discussion of the Goodrich paper, the late Mr. Gould remarked:†

"Another element which makes for safety, but which baffles calculation, is the clinging action of the material through which the

* Note that 100 lb. instead of 110 lb. per cu. ft. will give about 10 000 lb. smaller.

† *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 214.

pile is driven, and which action is set up immediately after it has been allowed to come to rest. It is often impossible to draw a defective pile even a very short time after it has been driven, unless a few blows be given by the hammer to start it, when it may come up very easily."

It is believed that the theory of the dilatancy of media composed of rigid particles in contact, as proposed by Professor Osborne Reynolds,* will account for this phenomenon noticed and recorded by many engineers. While the theory was formulated to account for the sub-mechanics of the universe, not the least of its claims is that it will place the theory of earth pressures on a true foundation. He says:

"I will point out the existence of a singular fundamental property of such granular media which is not possessed by known fluids or solids. * * * I have called this unique property of granular masses 'dilatancy,' because the property consists in a definite change of bulk, consequent on a definite change of shape or distortional strain, any disturbance whatever causing a change of volume and generally dilation.

"In the case of fluids, volume and shape are perfectly independent; and although in practice it is often difficult to alter the shape of any elastic body without altering its volume, yet the properties of dilation and distortion are essentially distinct, and are so considered in the theory of elasticity. In fact there are very few solid bodies which are to any extent dilatable at all.

"With granular media, the grains being sensibly hard, the case is, according to the results I have obtained, entirely different. So long as the grains are held in mutual equilibrium by stresses transmitted through the mass, every change of relative position of the grains is attended by a consequent change of volume; and if in any way the volume be fixed, then all change of shape is prevented."

The mathematics of this is long and difficult, in general. The essential features, as it is desired to apply them in reference to Mr. Gould's remarks, may be illustrated by the following experiment:

"If we have in a canvas bag any hard grains or balls, so long as the bag is not nearly full it will change its shape as it is moved about; but when the sack is approximately full a small change of shape causes it to become perfectly hard. There is perhaps nothing surprising in this, even apart from familiarity; because an inextensible sack has a rigid shape when extended to the full, any deformation diminishing its capacity, so that contents which did not fill the sack at its greatest extension fill it when deformed. On careful consideration, however, many curious questions present themselves.

* *Philosophical Magazine* (London, E., & D.), Vol. XX, 1885, pp. 469 *et seq.*; also Reynolds' Works, Vol. III.

"If, instead of a canvas bag, we have an extremely flexible bag of india-rubber, this envelope, when filled with heavy spheres (No. 6 shot), imposes no sensible restraint on their distortion; standing on the table it takes nearly the form of a heap of shot. This is apparently accounted for by the fact that the capacity of the bag does not diminish as it is deformed. In this condition it really shows us less of the qualities of its granular contents than the canvas bag. But as it is impervious to fluid, it will enable me to measure exactly the volume of its contents.

"Filling up the interstices between the shot with water so that the bag is quite full of water and shot, no bubble of air in it, and carefully closing the mouth, I now find that the bag has become absolutely rigid in whatever form it happened to be when closed.

"It is clear that the envelope now imposes no distortional constraint on the shot within it, nor does the water. What then, converts the heap of loose shot into an absolutely rigid body? Clearly, the limit which is imposed on the volume by the pressure of the atmosphere.

"So long as the arrangement of the shot is such that there is enough water to fill the interstices the shot are free, but any arrangement which requires more room is absolutely prevented by the pressure of the atmosphere * * *.

"The very finest quartz sand, or glass balls $\frac{3}{4}$ in. in diameter, all give the same results."

It would seem that such a state of affairs would tend to exist after the driving, in the final rearrangement of the particles in granular soils, and that the phenomenon may throw light on the case, as cited by Mr. Gould. It would further seem to favor an elastic theory, especially as one, to use another of Professor Reynolds' illustrations, may note the firmness of a sandy beach after the recession of a wave, in contradistinction to the quite fluid effect of the dry sand. The phenomenon deserves to be studied in its relation to the pile.

The writer was led to appreciate the importance of the static point of view, in the theory of the pile, through the suggestions of G. S. Williams, M. Am. Soc. C. E. He was introduced to the Boussinesq and Kötter theories* by Professor Alexander Ziwet. In making acknowledgment to these authorities and to Professor A. B. Pierce for discussion and criticism of these theories, the writer does not wish to be construed as committing them to these views.

* A number of solutions involving different phases of this problem may be easily found. Among these the writer would call attention to a treatment of the glacier by Hopkins, Cambridge Phil. Soc. *Transactions*, Vol. 8, 1849, in which he treats the glacier as an elastic body forcing its way between the walls of the valley, exerting lateral forces and friction on the sides of the stream quite comparable to the action of a pile in the earth. The Boussinesq literature, however, affords the most suggestion in addition to that of Kötter.

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS AND DISCUSSIONS

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FEDERAL INVESTIGATIONS OF MINE ACCIDENTS, STRUCTURAL MATERIALS, AND FUELS, AT THE UNITED STATES TESTING STATION, PITTSBURG, PA.

Discussion.*

By Messrs. Kenneth Allen, Henry Kreisinger, Walter O. Snelling, and A. Bartoccini.

Mr. Allen. Kenneth Allen, M. Am. Soc. C. E.—The speaker would like to know whether anything has been done in the United States toward utilizing marsh mud for fuel.

In an address by Mr. Edward Atkinson, before the New England Water Works Association, in 1904, on the subject of "Bog Fuel," he referred to its extensive use in Sweden and elsewhere, and intimated that there was a wide field for its use in America.

The percentage of combustible material in the mud of ordinary marsh lands is very considerable, and there are enormous deposits readily available; but it is hardly probable that its calorific value is sufficiently high to render its general use at this time profitable.

As an example of the amount of organic matter which may remain stored in these muds for many years, the speaker would mention a sample taken from the bottom of a trench, which he had analyzed a few years ago. Although taken from a depth of about 15 ft., much of the vegetable fiber remained intact. The material proved to be $70\frac{3}{4}\%$ volatile.

Possibly before the existing available coal deposits are exhausted, the exploitation of meadow muds for fuel may become profitable.

* This discussion (of the paper by Herbert M. Wilson, M. Am. Soc. C. E., printed in *Proceedings* for February, 1910, and presented at the meeting of April 20th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

HENRY KREISINGER, Esq.* (by letter). Mr. Wilson gives a brief description of a long furnace and an outline of the research work which is being done in it. It may be well to discuss somewhat more fully the proposed investigations and point out the practical value of the findings to which they may lead. Mr. Kreisinger.

In general, the object is to study the process of combustion of coal. When soft coal is burned in any furnace, part of the combustible is driven off shortly after charging, and has to be burned in the space between the fuel bed and the exit of the gases, which is called the combustion space. There is enough evidence to show that, with a constant air supply, the completeness of the combustion of the volatile combustible depends on the length of time the latter stays within the combustion space; but, with a constant rate of charging the coal, this length of time depends directly on the extent of the combustion space. Thus, if the volume of the volatile combustible evolved per second and the admixed air is 40 cu. ft., and the extent of the combustion space is 80 cu. ft., the average time the gas will stay within the latter is 2 sec.; if the combustion space is 20 cu. ft., the average time the mixture can stay in this space is only ½ sec., and its combustion will be less complete than in the first case. Thus it is seen that the extent of the combustion space of a furnace is an important factor in the economic combustion of volatile coals. The specific object of the investigations, thus far planned, is to determine the extent of the combustion space required to attain practically complete combustion when a given quantity of a given coal is burned under definite conditions. With this object in view, the furnace has been provided with a combustion space large enough for the highest volatile coals and for the highest customary rate of combustion. To illustrate the application of the data which will be obtained by these experiments, the following queries are given:

Suppose it is required to design a furnace which will burn coal from a certain Illinois mine at the rate of 1 000 lb. per hour, with a resulting temperature of not less than 2 800° Fahr. How large a combustion space is required to burn, with practical completeness, the volatile combustible? What completeness of combustion can be attained, if the combustion space is only three-fourths of the required extent? In the present state of the knowledge of the process of combustion of coal, these queries cannot be answered definitely. In the literature on combustion one may find statements that the gases must be completely burned before leaving the furnace or before they strike the cooling surfaces of the boiler; but there is no definite information available as to how long the gases must be kept in the furnace or how large the combustion space must be in order to obtain practically complete

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Mr. Kreisinger. combustion. It is strange that so little is known of such an old art as the combustion of coal.

The research work under consideration is fundamentally a problem in physical chemistry, and, for that reason, has been assigned to a committee consisting of the writer as Engineer, Dr. J. C. W. Frazer, Chemist, and Dr. J. K. Clement, Physicist. The outcome of the investigation may prove of extreme interest to mechanical and fuel engineers, and to all who have anything to do with the burning of coal or the construction of furnaces. In the experiments thus far planned the following factors will be considered:

Effect of the Nature of Coal on the Extent of Combustion Space Required.—The steaming coals mined in different localities evolve different volumes of volatile combustible, even when burned at the same rate. The coal which analyzes 45% of volatile matter evolves a much greater volume of gases and tar vapors than that analyzing only 15 per cent. These evolved gases and tar vapors must be burned in the space. Consequently, a furnace burning high volatile coal must have a much larger combustion space than that burning coal low in volatile combustible.

There is enough evidence to show that the extent of combustion space required to burn the volatile combustible depends, not only on the volume of the combustible mixture, but also on the chemical composition of the volatile combustible. Thus the volatile combustible of low volatile coal, when mixed with an equal volume of air, may require 1 sec. in the combustion space to burn practically to completeness, while it may require 2 sec. to burn the same volume of the volatile combustible of high volatile coal with the same completeness; so that the extent of the combustion space required to burn various kinds of coal may not be directly proportional to the volatile matter of the coal.

Effect of the Rate of Combustion on the Extent of Combustion Space Required.—With the same coal, the volume of the volatile combustible distilled from the fuel bed per unit of time varies as the rate of combustion. Thus, when this rate is double that of the standard, the volume of gases and tar vapors driven from the fuel is about doubled. To this increased volume of volatile combustible, about double the volume of air must be added, and, if the mixture is to be kept the same length of time within the combustion space, the latter should be about twice as large as for the standard rate of combustion. Thus the combustion space required for complete combustion varies, not only with the nature of the coal, but also with the rate of firing the fuel, which, of course, is self-evident.

Effect of Air Supply on the Extent of Combustion Space Required.—Another factor which influences the extent of the combustion space is the quantity of air mixed with the volatile combustible. Perhaps, within certain limits, the combustion space may be decreased when

the supply of air is increased. However, any statement at present is only speculation; the facts must be determined experimentally. One fact is known, namely, that, in order to obtain higher temperatures of the products of combustion, the air supply must be decreased. Mr. Kreisinger.

Effect of Rate of Heating of Coal on the Extent of Combustion Space Required.—There is still another factor, a very important one, which, with a given coal and any given air supply, will influence the extent of the combustion space. This factor is the rate of heating of the coal when feeding it into the furnace. The so-called "proximate" analysis of coal is indeed only very approximate. When the analysis shows, say, 40% of volatile matter and 45% of fixed carbon, it does not mean that the coal is actually composed of so much volatile matter and so much fixed carbon; it simply means that, under a certain rate of heating attained by certain standard laboratory conditions, 40% of the coal has been driven off as "volatile matter." If the rate or method of heating were different, the amount of volatile matter driven off would also be different. Chemists state that it is difficult to obtain accurate checks on "proximate" analysis. To illustrate this factor, further reference may be made to the operation of the up-draft bituminous gas producers. In the generator of such producers the tar vapors leave the freshly fired fuel, pass through the wet scrubber, and are finally separated by the tar extractor as a black, pasty substance in a semi-liquid state. If this tar is subjected to the standard proximate analysis, it will be shown that from 40 to 50% of it is fixed carbon, although it left the gas generator as volatile matter. It is desired to emphasize the fact that different rates of heating of high volatile coals will not only drive off different percentages of volatile matter, but that the latter itself varies greatly in chemical composition and physical properties as regards inflammability and rapidity of combustion. Thus it may be said that the extent of the combustion space required for the complete oxidation of the volatile combustible depends on the method of charging the fuel, that is, on how rapidly the fresh fuel is heated. If this factor is given proper consideration, it may be possible to reduce very materially the necessary space required for complete combustion.

The Effect of the Rate of Mixing the Volatile Combustible and Air on the Extent of the Combustion Space.—When studying the effects discussed in the preceding paragraphs, the rate of mixing the volatile combustible with the supply of air must be as constant as practicable. At first, tests will be made with no special mixing devices, the mixing will be accomplished entirely by the streams of air entering the furnace at the stoker, and by natural diffusion. Although there appears to be violent stirring of the gases above the fuel bed, the mixture of the gases does not become homogeneous until they are about 10 or 15 ft. from the stoker. The mixing caused by the air currents

Mr. Kreisinger. forced into the furnace at the stoker is very distinct, and can be readily observed through the peep-hole in the side wall of the Heine boiler, opposite the long combustion chamber. This mixing is shown in Fig. 20. *A* is a current of air forced from the ash-pit directly upward through the fuel bed; *B* and *B* are streams of air forced above the fuel bed through numerous small openings at the furnace side of each hopper. Those currents cause the gases to flow out of the furnace in two spirals, as shown in Fig. 20. The velocity of rotation on the outside of the two spirals appears to be about 10 ft. per sec., when

SECTION THROUGH STOKER SHOWING MIXING OF GASES CAUSED BY CURRENTS OF AIR

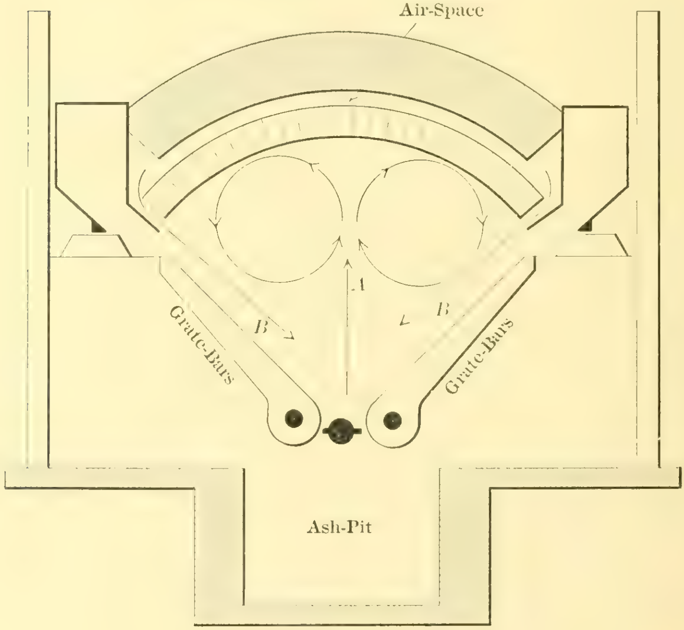

Fig. 20.

the rate of combustion is about 750 lb. of coal per hour. It is reasonable to expect that when the rate of mixing is increased by building piers and other mixing structures immediately back of the grate, the completeness of the combustion will be effected in less time, and a smaller combustion space will be required. Thus, the mixing structures may be an important factor in the extent of the required combustion space.

To sum up, it can be said that the extent of the space required

to obtain a combustion which can be considered complete for all practical purposes, depends on the following factors: Mr. Kreisinger.

(*a*).—Nature of coal,
(*b*).—Rate of combustion,
(*c*).—Supply of air,
(*d*).—Rate of heating fuel,
(*e*).—Rate of mixing volatile combustible and air.

Just how much the extent of the combustion space required will be influenced by these factors is the object of the experiments under discussion.

The Scope of the Experiments.—With this object in view, as explained in the perceding paragraphs, the following series of experiments are planned:

Six or eight typical coals are to be selected, each representing a certain group of nearly the same chemical composition. Each series will consist of several sets of tests, each set being run with all the conditions constant except the one, the effect of which on the size of the combustion space is to be investigated. Thus a set of four or five tests will be made, varying in rate of combustion from 20 to 80 lb. of coal per square foot of grate per hour, keeping the supply of air per pound of combustible and the rate of heating constant. This set will show the effect of the rate of combustion of the coal on the extent of space required to obtain combustion which is practically complete. Other variables, such as composition of coal, supply of air, and rate of heating, remain constant.

Another set of four or five tests will be made with the same coal and at the same rate of combustion, but the air supply will be different for each test. This set of tests will be repeated for two or three different rates of combustion. Thus each of these sets will give the effect of the air supply on the extent of combustion space when the coal and rate of combustion remain constant.

Still another set of tests should be made in which the time of heating the coal when feeding it into the furnace will vary from 3 to 30 min. In each of the tests of this set, the rate of combustion and the air supply will be kept constant, and the set will be repeated for two or three rates of combustion and two or three supplies of air. Each of these sets of tests will give the effect of the rate of heating of fresh fuel on the extent of combustion space required to burn the distilled volatile combustible. These sets of experiments will require a modification in the stoker mechanism, and, on that account, may be put off until all the other tests on the other selected typical coals are completed. As the investigation proceeds, enough may be learned so that the number of tests in each series may be gradually reduced. After all the desirable tests are made with the furnace as it stands, several

Mr. Kreisinger. kinds of mixing structures will be built successively back of the stoker and tried, one kind at a time, with a set of representative tests. Thus the effectiveness of such mixing structures will be determined.

Determining the Completeness of Combustion.—The completeness of combustion in the successive cross-sections of the stream of gases is determined mainly by the chemical analysis of samples of gases collected through the openings at these respective cross-sections. The first of these cross-sections at which gas samples are collected, passes through the middle of the bridge wall; the others are placed at intervals of 5 ft. through the entire length of the furnace. Measurements of the temperature of the gases, and direct observations of the length and color of the flames and of any visible smoke will be also made through the side peep-holes. These direct observations, together with the gas analysis, will furnish enough data to determine the length of travel of the combustible mixture to reach practically complete combustion.

In other words, these observations will determine the extent of the combustion space for various kinds of coal when burned under certain given conditions. Direct observations and the analysis of gases at sections nearer the stoker than that at which the combustion is practically complete, will show how the process of combustion approaches its completion. This information will be of extreme value in determining the effect of shortening the combustion space on the loss of heat due to incomplete combustion.

Method of Collecting Gas Samples.—The collection of gas samples is a difficult problem in itself, when one considers that the temperature of the gases, as they are in the furnace, ranges from 2 400° to 3 200° Fahr.; consequently, the samples must be collected with water-cooled tubes. Thus far, about 25 preliminary tests have been made. These tests show that the composition of the gases at the cross-sections near the stoker is not uniform, and that more than one sample must be taken from each cross-section. It was decided to take 9 samples from the cross-section immediately back of the stoker, and reduce the number in the sections following, according to the uniformity of the gas composition. Thus, about 35 simultaneous gas samples must be taken for each test. The samples will be subjected, not only to the usual determination of CO_2, O_2 and CO, but to a complete analysis. It is also realized that some of the carbon-hydrogen compounds which, at the furnace temperature, exist as heavy gases, are condensed to liquids and solids when cooled in the sampling tubes, where they settle and tend to clog it. To neglect the presence of this form of the combustible would introduce considerable error in the determination of the completeness of combustion at any of the cross-sections. Therefore, special water-cooled sampling tubes are constructed and equipped with filters which separate the liquid and solid combustible from the gases. The contents

of these filters are then also subjected to complete analysis. To obtain quantitative data, a measured quantity of gases must be drawn through these filtering sampling tubes. Mr. Kreisinger.

The Measuring of Temperatures. At present the only possible known method of measuring the temperature of the furnace gases is by optical and radiation pyrometers. Platinum thermo-couples are soon destroyed by the corrosive action of the hot gases. The pyrometers used at present are the Wanner optical pyrometer and the Fery radiation pyrometer.

The Flow of Heat Through Furnace Walls.—An interesting side investigation has developed, in the study of the loss of heat through the furnace walls. In the description of this experimental furnace it has been said that the side walls contained a 2-in. air space, which, in the roof, was replaced with a 1-in. layer of asbestos. To determine the relative resistance to heat flow of the air space and the asbestos layer, 20 thermo-couples were embedded, in groups of four, to different depths at three places in the side wall and at two places in the roof. In the side wall, one of the thermo-couples of each group was placed in the inner wall near the furnace surface; the second thermo-couple was placed in the same wall, but near the surface facing the air space; the third thermo-couple was placed in the outer wall near the inner surface; and the fourth was placed near the outer surface in the outer wall. In the roof the second and third thermo-couples were placed in the brick near the surface on each side of the asbestos layer. These thermo-couples have shown that the temperature drop across the 2-in. air space was much less than that across the 1-in. layer of asbestos; in fact, that it was considerably less than the temperature drop through the same thickness of the brick wall.

The results obtained prove that, as far as heat insulation is concerned, air spaces in furnace walls are undesirable. The heat is not conducted through the air, but leaps across the space by radiation. In furnace construction a solid wall is a better heat insulator than one of the same total thickness containing an air space. If it is necessary to build a furnace wall in two parts on account of unequal expansion, the space between the two walls should be filled with some solid, cheap, non-conducting materials, such as ash, sand, or crushed brick. A more detailed account of these experiments may be found in a Bulletin of the U. S. Geological Survey entitled "The Flow of Heat Through Furnace Walls."

WALTER O. SNELLING, ESQ.* (by letter).—The work of the United States Testing Station at Pittsburg has been set forth so fully by Mr. Wilson that a further statement as to the results achieved may seem like repetition. It would be most unlikely, however, that studies Mr. Snelling.

* Chief Explosives Chemist, U. S. Geological Survey.

Mr. Snelling. of such variety should possess no other value than along the direct lines being investigated. In the case of the Mine Accidents Division, at least, it is certain that the indirect benefits of some of the studies have been far-reaching, and are now proving of value in lines far removed from those which were the primary object of the investigation. They are developing facts which will be of great value to all engineers or contractors engaged in tunneling or quarrying. As the writer's experience has been solely in connection with the chemical examination of explosives, he will confine his discussion to this phase.

In studying the properties of various explosives, and in testing work to separate those in which the danger of igniting explosive mixtures of coal dust and air, or of fire-damp and air, is greatest, from those in which this danger is least, much information has been collected. Mr. Wilson has described many of the tests, and it can be readily seen that in carrying out these and other tests on each of the explosives submitted, a great many facts relating to the properties of explosive compounds have been obtained, which were soon found to be of decided value in directions other than the simple differentiation of explosives which are safe from those which are unsafe in the presence of explosive mixtures of fire-damp or coal dust.

The factors which determine the suitability of an explosive for work in material of any particular physical characteristics depend on the relationship of such properties as percussive force (or the initial blow produced by the products of the decomposition of the explosive at the moment of explosion), and the heaving force (or the continued pressure produced by the products of the decomposition, after the initial blow at the instant of detonation). Where an explosive has been used in coal or rock of a certain degree of brittleness, and where the work of the explosive with that particular coal is not thoroughly satisfactory, it becomes evident that through the systematic use of the information available at the Testing Station (and now in course of publication in the form of bulletins), in regard to the relationship between percussive and heaving forces in different explosives, as shown by the tests with small lead blocks, the Trauzl test, and the ballistic pendulum, that explosives can be selected which, possessing in modified form the properties of the explosive not entirely satisfactory in that type of coal or rock, would combine all the favorable properties of the first explosive, together with such additional advantages as would come from its added adaptation to the material in which it is to be used.

For example, if the explosive in use were found to have too great a shattering effect on the coal, an examination of the small lead-block test of this explosive, and a comparison of this with lead-block tests of other explosives having practically the same strength, as shown by the ballistic pendulum, will enable the mine manager to select from those already on the Permissible List (and therefore vouched for in

regard to safety in the presence of gas and coal dust, when used in a proper way), some explosive which will have the same strength, and yet which, because of lessened percussive force or shattering effect, will produce coal in the manner desired. If one takes the other extreme, and considers a mine in which the product is used exclusively for the preparation of coke (and therefore where shattering of the coal is in no way a disadvantage), the mine superintendent's interest will be primarily to select an explosive which, as indicated by suitable lead-block, Trauzl, and ballistic pendulum tests, will produce the greatest amount of coal at the least cost. Mr. Snelling.

As the cost of the explosive does not form any part of the tables prepared by the Testing Station, the relative cost must be computed from the manufacturer's prices, but the results tabulated by the Station will contain all the other data necessary to give the mine superintendent (who cares to take the small amount of trouble necessary to familiarize himself with the tables) all the information which is required to compare the action of one explosive with that of any other explosive tested.

In this way it is seen that, aside from the primary consideration of safety in the presence of explosive mixtures of fire-damp and coal dust (a condition alike fulfilled by all explosives admitted to the Permissible List), the data prepared by the Testing Station also give the information necessary to enable the discriminating mine manager to select an explosive adapted to the particular physical qualities of the coal at his mine, or to decide intelligently between two explosives of the same cost on the basis of their actual energy content in the particular form of the heaving or percussive force required in his work.

Up to the present time the investigations have been confined to explosives used in coal mining, because the Act of Congress establishing the Testing Station has thus limited its work. Accordingly, it is not possible to compare, on the systematic basis just mentioned, the explosives generally used in rock work. It is probable that, if the Bill now before Congress in regard to the establishment of a Bureau of Mines is passed, work of this character will be undertaken, and the tables of explosives now prepared will be extended to cover all those intended for general mining and quarrying use. Data of such character are unobtainable to-day, and, as a result, a considerable percentage of explosives now used in all mining operations is wasted, because of their lack of adaptation to the materials being blasted. It is well known, for example, that when an explosive of high percussive force is used in excavating in a soft or easily compressed medium, a considerable percentage of its force is wasted as heat energy, performing no other function than the distortion and compression of

Mr. Snelling. the material in which it is fired, without exerting either an appreciable cracking or fissuring effect, or a heaving or throwing of the material.

Owing to lack of information in regard to the exact relationship between the percussive and the heaving force in particular explosives, this waste, as compared with the quantity required for the work with a properly balanced material, will continue; but it is to be hoped that it will soon be possible to give the mining and quarrying industries suitable information in regard to the properties of the various explosives, so that the railroad contractor and the metal miner may have the same simple and exact means of discrimination between suitable and unsuitable explosives that is now being provided for the benefit of the coal miner.

Another of the important but indirect benefits of this work has been the production of uniformity of strength and composition in explosives. An example of this helpful influence is the standardization of detonating caps and electric detonators. In the early days of the explosive industry, it was apparently advantageous for each manufacturer to have a separate system of trade nomenclature by which to designate the strengths of the different detonators manufactured by him. The necessity and even the advantage of such methods have long been outgrown, and yet, until the past year, the explosive industry has had to labor under conditions which made it almost impossible for the user of explosives to compare, in cost or strength, detonators of different manufacturers; or to select intelligently the detonator best suited to the explosive to be used. After conference with the manufacturers of detonating caps and electric detonators, a standard system of naming the strengths of these products has been selected by the Testing Station, and has met with a most hearty response. It is encouraging to note that, in recent trade catalogues, detonators are named in such a way as to enable the user to determine directly the strength of the contained charge, which is a decided advantage to every user of explosives and also to manufacturers.

The uniformity of composition of explosives (and many difficulties in mining work and many accidents have been rightly or wrongly attributed to lack of uniformity) may be considered as settled in regard to all those on the Permissible List. One of the conditions required of every explosive on that list is that its composition must continue substantially the same as the samples submitted originally for official test. Up to the present, all explosives admitted to the Permissible List have maintained their original composition, as determined by subsequent analyses of samples selected from mines in which the explosive was in use, and comparison with the original samples.

The data assembled by the Testing Station in regard to particular explosives have also been of great benefit to the manufacturers. When

Mr. Snelling.

the explosives tests were commenced, comparatively few explosives were being made in the United States for which it was even claimed by the manufacturers that they were at all safe in the presence of explosive mixtures of gas or coal dust. It was evident that, without systematic tests, very little knowledge of the safety or lack of safety of any particular explosive could ever be gained, and, consequently, the user of explosives was apt to regard with incredulity any claim by the manufacturer in regard to the qualities of safety. Owing to lack of proof, this was most natural; and it was also evident that the very slow process of testing, which was offered by a study of mine explosions during past years, was sufficient only to prove the danger of black powder, and not in any way to indicate the safety of any of the brands of mining powder for which this property was claimed. Indeed, one of the few explosives to which the name, "safety," was attached, at the time the Government experiments were first undertaken, was found to be anything but safe when tested in the gallery, although there is no reason to believe that the makers of this and other explosives claiming "safety" for their product, did not have the fullest confidence in their safety.

The Testing Station offered the first opportunity in the United States to obtain facts in regard to the danger of any particular explosive in the presence of explosive mixtures of gas or coal dust. With most commendable energy, the manufacturers of explosives, noting the early failures of their powders in the testing gallery, began at once to modify them in such ways as suggested by the behavior of the explosives when under test, and, in a short time, returned to the Testing Station with improved products, able to stand the severe tests required. In this way the Testing Station has been a most active agent in increasing the general safety of explosives, and the manufacturers have shown clearly that it never was their desire to offer inferior explosives to the public, but that their failures in the past were due solely to lack of information in regard to the action of explosives under the conditions which exist before a mine disaster. The chance being offered to duplicate, at the Testing Station, the conditions represented in a mine in the presence of gas, they showed an eagerness to modify and improve their explosives so as to enable them to answer severe mining conditions, which is most commendable to American industry.

In regard to the unfavorable conditions existing in mines in the past, the same arguments may be used. In spite of the frequency of mine accidents in the United States, and in spite of the high death rate in coal mining as compared with that in other countries, it must be said in fairness that this has been the result of ignorance of the actual conditions which produce mine explosions, rather than any willful disregard of the known laws of safety by mine owners. Condi-

Mr. Snelling. tions in American mines are far different from those obtaining in mines abroad, and, as a result, the rules which years of experience had taught to foreign colliery managers were not quickly applied to conditions existing in American mines; but, as soon as the work at the Pittsburg Station had demonstrated the explosibility of the coal dust from adjoining mines, and had shown the very great safety of some explosives as compared with others, there was at once a readiness on the part of mine owners throughout the country to improve conditions in their mines, and to take advantage of all the studies made by the Government, thus showing clearly that the disasters of the past had been due to lack of sufficient information rather that to any willful disregard of the value of human lives.

Another of the indirect benefits of the work of the Station has resulted from its examination of explosives for the Panama Canal. For several years the Isthmian Canal Commission has been one of the largest users of explosives in the world, and, in the purchase of the enormous quantities required, it was found necessary to establish a system of careful examination and inspection. This was done in order to insure the safety of the explosives delivered on the Isthmus, and also to make certain that the standards named in the contract were being maintained at all times. With its established corps of chemists and engineers, it was natural that this important work should be taken up by the Technologic Branch of the United States Geological Survey, and, during the past three years, many millions of pounds of dynamite have been inspected and samples analyzed by the chemists connected with the Pittsburg Testing Station, thus insuring the high standard of these materials.

One of the many ways in which this work for the Canal Commission has proved of advantage is shown by the fact that, as a result of studies at the Testing Station, electric detonators are being made to-day which, in water-proof qualities, are greatly superior to any similar product. As the improvements of these detonators were made by a member of the testing staff, all the pecuniary advantages arising from them have gone directly to the Government, which to-day is obtaining superior electric detonators, and at a cost of about one-third of the price of the former materials.

All the work of the Technologic Branch is being carried out along eminently practical lines, and is far removed from such work as can be taken up advantageously by private or by State agencies. The work of the Mine Accidents Division was taken up primarily to reduce the number of mine accidents, and to increase the general conditions of safety in mining. As the work of this Division has progressed, it has been found to be of great advantage to the miner and the mine owner, while the ultimate results of the studies will be of still greater value to every consumer of coal, as they will insure a continued supply of this valuable product, and at a lower cost than if the present

methods, wasteful alike in lives and in coal, had been allowed to continue for another decade. Mr. Snelling.

A. Bartoccini, Assoc. M. Am. Soc. C. E. (by letter).—The writer made a personal investigation of the mine disaster of Cherry, Ill. He interviewed the men who escaped on the day of the accident, and also several of those who were rescued one week later. He also interrogated the superintendent and the engineer of the mine, and obtained all the information asked for and also the plans of the mine showing the progress of the work. Mr. Bartoccini.

After a careful investigation the writer found that the following conditions existed at the mine at the time of the disaster:

First.—There were no means for extinguishing fires in the mine.

Second.—There were no signal systems of any kind. Had the mine been provided with electric signals and telephones, like some of the most modern mines in the United States, the majority of the men could have been saved, by getting into communication with the outside and working in conjunction with the rescuers.

Third.—The miners had never received instructions of how to behave in case of fire.

Fourth.—The main entries and stables were lighted with open torches.

Fifth.—The organization of the mine was defective in some way, for at the time of the disaster orders came from every direction.

Sixth.—The air shaft was used also as a hoisting shaft.

Seventh.—The main shaft practically reached only to the second vein; its extension to the third and deepest vein was not used.

Eighth.—Plans of the workings of the second and third veins were not up to date. The last survey recorded on them was that of June, 1909. This would have made rescue work almost impossible to men not familiar with the mine.

Ninth.—The inside survey of the mine was not connected with the outside survey.

Would it not be possible for the United States Geological Survey to enforce rules which would prevent the existence of conditions such as those mentioned? The Survey is doing wonderful work, as shown by the rescue of twenty miners at Cherry one week after the conflagration; but there is no doubt that perhaps all the men could have been saved if telephone communications with the outside had been established. Telephone lines to resist any kind of a fire, can easily be installed, and the expense is small, almost negligible when one considers the enormous losses suffered by the mine owners and by the families of the victims.

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PAPERS AND DISCUSSIONS

THE WATER SUPPLY OF THE EL PASO AND SOUTHWESTERN RAILWAY FROM CARRIZOZO TO SANTA ROSA, N. MEX.

Discussion.*

By G. E. P. Smith, Assoc. M. Am. Soc. C. E.

Mr. Smith. G. E. P. Smith, Assoc. M. Am. Soc. C. E. (by letter).—The author has done great service to the West in demonstrating the practicability of transporting small water supplies to great distances.

Close association with the desert is required to appreciate fully its waterless condition. For most of the year there are no living waters on the surface. As a rule ground-waters are concentrated beneath very limited areas of valley land. The great masses of valley fill in some places are underdrained to great depths and in other places are so compacted and cemented as to be impervious. Wells sometimes are driven from 1 000 to 2 000 ft., without securing any supply at all. Moreover, desert ground-waters are often exceedingly hard or alkaline, and, therefore, are unfit for many uses.

In going to the high mountains for a supply, the author has struck a principle of wide application. In many of the mountains of the Southwest there are springs and small streams of excellent water. Often, as in the case discussed, very little storage is required. These streams, however, are absorbed or disappear before reaching even the mouths of the cañons, and the problem has been to convey the water to distant cities and mining camps at reasonable cost. There are several cities in Arizona now possessing pumped water supplies, which

*This discussion (of the paper by J. L. Campbell, M. Am. Soc. C. E., printed in *Proceedings* for March, 1910, and presented at the meeting of May 4th, 1910), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

have possible gravity supplies of superior quality. The writer believes that ultimately the gravity supplies will replace the pumping plants. Mr. Smith.

In the Bonita pipe line, wood-stave pipe was used for the gravity sections. In other localities, where the grade of the line is very uniform, as would be the case down a typical clinoplain, cement pipe is deserving of consideration. It would cost no more than wood stave, would be more durable, and, furthermore, it need have no greater leakage. Its cost, however, increases rapidly when built to withstand high pressures.

The use of bran for determining velocities is of interest. The results are in close accord with those obtained from the weir measurements. In the measurement of ground-water velocities by means of salts in solution, it is found that the velocities of different filaments of waters are extremely variable, and a quart of salt solution, after moving forward a few feet, is widely dispersed. It would be of value to know to what extent the bran was distributed during its 4-hour journey through the pipe line, and during how many minutes it was being discharged at the lower end of the line. Was the first appearance, or the average time of appearance, accepted for computing the velocity of flow?

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PAPERS AND DISCUSSIONS

LOCOMOTIVE PERFORMANCE ON GRADES OF VARIOUS LENGTHS.

Discussion.*

By C. D. Purdon, M. Am. Soc. C. E.

Mr. Purdon.

C. D. Purdon, M. Am. Soc. C. E. (by letter).—Some years ago the writer, in making studies for grade revision, found that the tractive power of a locomotive up grade becomes less as the length of the grade increases, and in some unknown proportion. This was a practical confirmation of the saying of locomotive engineers, that the engine "got tired" on long grades. On a well-known Western railroad, with which the writer is familiar, experiments were made for the purpose of rating its locomotives. The locomotives were first divided into classes according to their tractive power, this being calculated by the usual rule, with factors of size of cylinders, boiler pressure, and diameter of drivers, also by taking one-fourth of the weight on the drivers, and using the lesser of the two results as the tractive power.

Locomotives of different classes, and hauling known loads, were run over a freight division, the cars being weighed for the purpose; thus the maximum load which could be handled over a division, or different parts of a division, was ascertained, and this proportion of tonnage to tractive power was used in rating all classes.

Of course, this method was not mathematically accurate, as the condition of track, the weather, and the personal equation of the locomotive engineers all had an effect, but, later, when correcting the rating by tests with dynamometers, it was found that the results were fairly practical.

* This discussion (of the paper by Beverly S. Randolph, M. Am. Soc. C. E., printed in *Proceedings* but not presented at any meeting) is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

There were three hills where the rate of grade was the same as the rest of the division, but where the length was much in excess of other grades of the same rate. Mr. Purdon.

Designating these hills as *A*, *B*, and *C*, the lengths are, respectively, 2.44, 3.57, and 4.41 miles. There were no other grades of the same rate exceeding 1 mile.

In one class of freight engines, 10-wheel Brooks, the weight of the engine was 197 900 lb.; tender, 132 800 lb.; weight on drivers, 142 600 lb.; boiler pressure, 200 lb.; and tractive power of cylinders, 33 300 lb.

On Hill *A* these engines are rated at 865 tons, as compared with 945 on other parts of the division. As the engine weighs 165 tons and the caboose 15 tons, 180 tons should be added, making the figures, 1 045 and 1 125 tons. Thus the length of the grade, 2.44 miles, makes the tractive power on it 92% of that on shorter grades.

On Hill *B*, the rating, adding 180 tons as above, is 1 160 and 1 230 tons, respectively, giving 94% for 3.57 miles.

On Hill *C*, the rating, with 180 tons added, is 1 130 and 1 230 tons, making 92% for 4.41 miles.

Taking the same basis as the author, namely, 4.7 lb. per ton, rate of grade × 20, and weight on drivers, gives:

Hill *A*, 18.078%,	remainder	of	division,	19.462%
Hill *B*, 20.068%,	"	"	"	21.279%
Hill *C*, 19.549%,	"	"	"	21.279%

It will be noted that the author uses the weight on the drivers as the criterion, but the tractive power is not directly as the weight on the drivers, some engines being over-cylindered, or under-cylindered; in the class of engines above mentioned the tractive power is 23.35% of the weight on the drivers.

The writer made a study of several dynamometer tests on Hill *C*. There is a grade of the same rate, about 1 mile long, near this hill, and a station near its foot, but there is sufficient level grade between this station and the foot of the hill to get a good start.

All the engines of the above class, loaded for Hill *C*, gained speed on the 1-mile grade, but began to fall below the theoretical speed at a point about 2¼ miles from the foot of the hill. This condition occurred when the trains stopped at the station and also when they passed it at a rate of some 16 or 18 miles per hour, the speed becoming less and less as the top of the hill was approached.

The writer concludes that the author might stretch his opinion as to using heavier rates of grade on shorter hills than 10 miles, and indeed his diagram seems to intimate as much, and that, for economical operation, the maximum rate of grade should be reduced after a length of about 2 miles has been reached, and more and more in

Mr. Purdon. proportion to the length of the hill, in order that the same rating could be applied all over a division.

This conclusion might be modified by local conditions, such as an important town where cars might be added to or taken from the train.

While it does not seem practicable to the writer to calculate what the reduction of rate of grade should be, a consensus of results of operation on different lengths of grade might give sufficient data to reach some conclusion on the matter.

The American Railway Engineering and Maintenance of Way Association has a Committee on "Railway Economics," which is studying such matters, but so far as the writer knows it has not given this question any consideration.

The writer hopes that the author will follow up this subject, and that other members will join, as a full discussion will no doubt bring some results on a question which seems to be highly important.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will be reproduced in the volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

JOHN FISKE BARNARD, M. Am. Soc. C. E.*

DIED FEBRUARY 6TH, 1910.

John Fiske Barnard was born in Worcester, Mass., on April 23d, 1829. He was graduated from the Bridgewater Normal School, and from Rensselaer Polytechnic Institute.

In November, 1850, Mr. Barnard entered the railway service. He held various engineering and operating positions with the Grand Trunk Railway and its subsidiary lines in Lower Canada, and served as Chief Engineer of the Grand Trunk South of the St. Lawrence River for the last three years of his connection with that road.

In May, 1869, he went to the Missouri Valley Railroad as Superintendent and Chief Engineer. During the same year he was appointed Chief Engineer of the Kansas City-St. Joseph and Council Bluffs Railroad, and remained with this road and the Hannibal and St. Joseph Railroad (both now a part of the Burlington Missouri Lines), as Chief Engineer, General Superintendent, and General Manager, until 1886. During this time Mr. Barnard was also President of the Atchison Union Depot Company and the St. Joseph Union Stock Yards Company, Secretary and Treasurer of the St. Joseph Depot Company, and Director in various railroad companies.

In 1886, Mr. Barnard was appointed President and General Manager of the Ohio and Mississippi Railway, which position he occupied until 1892. From that time until 1893, he was engaged on several reports of projected railroads and appraisals of industrial and railroad properties.

From 1893 to 1898, Mr. Barnard was Receiver of the Omaha and St. Louis (now Wabash) Railway, during part of which time he was also President of the Alton Bridge Company, and Receiver of the St. Clair-Madison and St. Louis Belt Line.

In the spring of 1905 he moved to Los Angeles, Cal., where he lived until February 6th, 1910, when, after an illness of several months, he died at his home at the age of 81 years.

Mr. Barnard was elected a Member of the American Society of Civil Engineers on September 1st, 1880. He was also a Member of the American Geographical Society.

* Memoir prepared by W. K. Barnard, Assoc. M. Am. Soc. C. E.